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THE LETHAL WAR GASES: PHYSIOLOGY AND EXPERIMENTAL TREATMENT

BY THE SAME AUTHOR:

The Physiology of the Amino Acids

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THE
LETHAL WAR GASES

PHYSIOLOGY AND EXPERIMENTAL TREATMENT

AN INVESTIGATION BY THE SECTION ON INTERMEDIARY
METABOLISM OF THE MEDICAL DIVISION OF THE
CHEMICAL WARFARE SERVICE AT YALE
UNIVERSITY UNDER THE DIRECTION OF

FRANK P. UNDERHILL
RECENTLY LIEUTENANT-COLONEL CHEMICAL WARFARE SERVICE UNITED STATES ARMY
PROFESSOR OF EXPERIMENTAL MEDICINE SCHOOL OF MEDICINE YALE UNIVERSITY

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THE ANTHONY N. BRADY MEMORIAL FOUNDATION

THE present volume is the second work published by the Yale University Press on the Anthony N. Brady Memorial Foundation, which was established June 15, 1914, by members of the family of the late Anthony N. Brady to enable the University to declare operative the agreement for an alliance between the New Haven Hospital and the Yale School of Medicine. In addition to the pledge of endowment for this purpose the donors erected for the University on the grounds of the Hospital a clinical and pathological laboratory, and have since, through additional gifts to supplement the income of the Memorial Foundation, made possible the publication of this and other works by members of the Faculty of the School of Medicine at Yale.

ACKNOWLEDGMENTS

WHATEVER merit this volume may contain is due in large measure to the fine spirit of coöperation and personal interest of each individual comprising the section.

Especially should credit be given to Professor Lorande Loss Woodruff, Professor Henry Laurens, Captain George A. Baitsell, Captain Samuel Goldschmidt, Captain David Wright Wilson, 1st Lieutenant Henry D. Hooker, Jr., 1st Lieutenant Carl H. Greene, 2d Lieutenant Arthur H. Smith, and 2d Lieutenant Alfred Chanutin.

During the absence of the writer in France Professor Woodruff was left in general charge; Captain Baitsell and Professor Laurens had direct supervision over the scientific work. To Captains Goldschmidt, Wilson and Baitsell, and to Lieutenants Hooker, Greene, Smith, and Chanutin is due largely the evolution of treatment herein outlined.

Invaluable assistance was furnished by Yale University in supplying the necessary laboratory facilities and in releasing men from the University to devote their time to the problems under investigation.

It is a particular pleasure to the writer to acknowledge indebtedness to Director Van H. Manning, Major General Wm. L. Sibert, Colonel George A. Burrell, and Colonel Wm. J. Lyster for freedom of action and sympathetic coöperation extended throughout the period of investigation.

PREFACE

With the entrance of the United States into the war a small group of men connected with the Bureau of Mines were appointed a committee by Director Van H. Manning for the purpose of investigating toxic gases employed in warfare. The Chairman of the committee was George A. Burrell (later Colonel Burrell), who was designated Assistant to the Director. To Professor Yandell Henderson of Yale University was given the task of organizing the Medical Division to study the physiological effects of war gases and the institution of therapeutic measures.

The importance of the investigation is attested by the extremely rapid growth of the organization, the chemical branch of which was finally located at the American University in Washington, the Medical Division having Yale University for its center. This organization, developed under the Director of the Bureau of Mines, was supplied with funds by the Army and Navy, and formed the nucleus of what was later known as the Chemical Warfare Service, the War Department creating such a branch of the Army by absorption of this portion of the Bureau of Mines.

So long as the organization retained a civilian personnel the work was under the direction of Director Manning, Professor Yandell Henderson serving as Chairman of the Medical Division. With the transfer of the organization to the War Department Major General Wm. L. Sibert became Director of the Chemical Warfare Service, and Colonel Wm. J. Lyster was appointed Officer in Charge of the Medical Division. For the purposes of this volume a recital of the various ramifications of the branches of the war gas investigation would lead too far afield; the immediate interest attaches to the development of the Medical Division. The Medical Division as first instituted comprised four sections as follows:

Physiology: Chief, Yandell Henderson
Pharmacology and Therapeutics: Chief, Henry G. Barbour
Pathology: Chief, Milton C. Winternitz
Pathological Chemistry: Chief, Frank P. Underhill

Later the section of Pharmacology and Therapeutics was reorganized, the subject of Pharmacology being removed to Washington and placed under the direction of Doctor E. K. Marshall, Doctor Barbour having withdrawn from the work. The subject of Therapeutics was transferred to the section of Pathological Chemistry. Still later the latter section was designated the section on Intermediary Metabolism. Later other sections were added to the Medical Division, various universities coöperating.

In its initial stage the section of which the writer was Chief consisted of six men, namely: Samuel Goldschmidt, David Wright Wilson, Carl H. Greene, Henry D. Hooker, Jr., Alfred Chanutin, and Arthur H. Smith. In its final form this section was divided into the following units, each with its respective personnel:

Literature and Data:
Professor L. L. Woodruff
Private Helmut C. Diehl

Purchases and Supplies:
Sergeant Waldo L. Daniels
Corporal Ray E. J. Fulton

Blood Gases:
2d Lieutenant Arthur H. Smith
2d Lieutenant Barnett Cohen
Private Arthur Head

Blood Elements:
2d Lieutenant Alfred Chanutin
Sergeant Wm. J. Schoenwetter
Private Samuel B. Yacknowitz

Tissues:
George E. Simpson
Private Carl F. Hanske
Private Francis A. Gilfillan

Metabolism:
Walter G. Karr
Private Theodore F. Zucker

Clinical Studies and Treatment:
Captain George A. Baitsell
Corporal Ray E. Phillips
Corporal Cecil A. Smith
Private Jesse Goodman
Private Paul C. Gwinn

Oxygen Treatment:
Professor Henry Laurens
Sergeant James A. Dawson
Private Harold D. Rhynedance
Private Gordon G. Allison
Private Clifford M. Drury
Private Joseph J. Donohue

General Treatment:
1st Lieutenant Carl H. Greene
1st Lieutenant Henry D. Hooker, Jr.
Corporal Eugene A. Krauss
Private Joseph M. Russ
Private Thomas B. Stansel

Gassing of Animals:
2d Lieutenant Wm. J. Horn
2d Lieutenant Edwin J. Fischer
Sergeant Frederick J. Kenny
Private Harry Caplovitz
Frederick T. Gilbert
Private L. M. Aycock
Private Carl E. Robinson

Early in 1918 Doctors Goldschmidt and Wilson received commissions as 1st Lieutenants in the National Army, and were sent to France with the results obtained up to that time. Later they were assigned to continue this line of work with the British Chemical Warfare Committee at Porton, England, where they remained until just before the close of the war. Shortly after the transfer of the Bureau of Mines to the War Department the writer accepted a commission as Lieutenant-Colonel and became Commanding Officer of the Yale Station. At this period efforts were made to militarize the entire organization, an endeavor which was consummated for the most part, nearly all the men finally being in uniform.

The results obtained by this Section along therapeutic lines by September, 1918, warranted a clinical trial in the field. Accordingly the writer, accompanied by Lieutenants Hooker, Greene, Smith, and Chanutin, was ordered to France to institute such a test. With the cordial coöperation of the Army Medical Department the various hospitals treating gassed cases in the areas of the First and Second Armies were visited in an attempt to obtain the optimum conditions for testing the treatment.

Before data in this direction could be obtained the Armistice was signed. A sufficient number of gassed men were observed, however, to demonstrate the similarity of their condition to that of the experimental cases. The successful treatment of the latter by the therapeutic measures evolved made probable an equally successful outcome of the proposed trial in the field with human cases of gas poisoning.

In the presentation of the subject-matter herein contained it should be emphasized that no attempt has been made to correlate the data cited with the work of other investigators. It is impossible to do this in an adequate manner at present, owing to the fact that much of the material is either unavailable or uncertainty exists relative to its release for publication. This volume therefore partakes more of the nature of a report of work accomplished than a complete discussion of the many problems outlined.

FRANK P. UNDERHILL.

December, 1918.

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CHAPTER I

THE USE OF LETHAL GASES

SUBSEQUENT to the gas attack of April, 1915, by the German Army poisonous gases for offensive purposes were extensively used throughout the period of the war. At first these gases, compressed into cylinders, were liberated with the formation of a cloud, dependence being placed upon the wind to carry the gas in the direction desired. Later the gas shell was introduced. The gas shell has distinct advantages over the gas cloud. In the first place, gas shells can be used in wind blowing in any direction, although the strength of the wind has considerable influence on the effective use of the shells. Secondly, the gas shell allows the use of a great number of compounds that could not be employed to form a cloud. The great majority of gases used in shells are liquids of high boiling point which are transformed into vapor by the bursting of the shell, and which remain for some time on the ground bombarded, slowly giving off the active vapor. For certain obvious purposes gas has also been used in trench mortar bombs and in hand grenades. The gases most commonly used are of four main varieties.

1. Asphyxiant or suffocative gases. For example—Chlorine, Phosgene ($COCl_2$), Di-phosgene, Chlorpicrin (CCl_3NO_2).
2. Tear gases or lachrymators. For example—Xylyl and Benzyl Bromide.
3. Sneezing gases or sternutators. For example—Diphenylchlorarsine.
4. Blistering gases or vesicants. For example—Dichlorethylsulphide $(C_2H_4Cl)_2S$ (mustard gas or yperite).

The asphyxiant gases are the most deadly and hence may be placed in a class by themselves under the name of Lethal Gases. In general the remaining gases, while producing fatalities under suitable conditions, have been employed mainly to harass troops and render them less efficient, either by forcing them to wear masks or else by causing the formation of blisters on the skin. The gases not included in the Lethal group have been called the Neutralizing group from the fact that contact with them tends to neutralize or diminish the efficiency of troops.

The gases of interest in the present discussion are three in number—Chlorine, Phosgene, and Chlorpicrin. The first cloud attacks were all made with chlorine, but later the German gas cloud was composed of chlorine and phosgene in varying proportions, usually from 20 per cent to 25 per cent phosgene. In shells the gases were usually mixtures such as phosgene and chlorpicrin, arsines, phosgene and di-phosgene, di-phosgene and chlorpicrin. On the other hand, many shells containing only phosgene were employed.

Chlorine

Chlorine is a greenish yellow gas somewhat soluble in water, one volume of water at 10° C. dissolving 2.5 volume of gas. The gas is two and one-half times as heavy as air; it is a strong respiratory irritant and lachrymator. Under suitable conditions it condenses to a yellow liquid which, if perfectly dry, can be stored in steel cylinders. Chlorine was not used in gas shells. In the gaseous state chlorine has marked asphyxiating properties.

Phosgene

Phosgene or carbonyl chloride ($COCl_2$) is a colorless gas with a peculiar odor described as that of "musty hay" by which it may be recognized. Tobacco smoked by an individual who has been subjected to phosgene has an unpleasant and objectionable taste. This constitutes the so-called tobacco reaction. Phosgene was first prepared by exposing a mixture of equal parts of carbon monoxide and chlorine to sunlight. The name phosgene was given the gas to suggest the part played by light in its formation. Phosgene is less irritating to the nose and eyes than chlorine, and is less likely to cause immediate asphyxia. But it is regarded as a more effective fighting weapon as its use leads to a large number of casualties and deaths.

The toxic action of phosgene is slower than that of chlorine, probably because to produce its effects it must undergo hydrolysis. On the point of how phosgene acts in the body there is a considerable difference of opinion. According to some investigators phosgene is absorbed as such by the cells, being gradually hydrolyzed with the formation of hydrochloric acid. This would explain the severe damage found in the bronchioles and alveoli of the lungs, and would also account for the slower and the more gradual development of the signs of pulmonary injury. Chlorine on the other hand does not need this preliminary decomposition, hence its action is more rapid. Other observers believe that phosgene is immediately hydrolyzed in the lungs, the moisture present being sufficient to bring about this reaction. Hydrochloric acid and phosgene do not produce the same lesions, either in degree or kind, a fact which would tend to militate against the view that hydrochloric acid, formed from the hydrolysis of phosgene, is the effective agent.

Phosgene is a liquid at a temperature of 8.2° C., with a specific gravity of 1.432. It is not absorbed by so large a variety of substances as chlorine, but on the other hand readily reacts with amines such as—Aniline, Hexamethylenetetramine, and Pyridine.

Chlorpicrin

Chlorpicrin or nitrochloroform (CCl_3NO_2) is a colorless liquid, almost insoluble in water, but soluble in alcohol. Its vapor explodes when superheated, but it can be distilled in a current of steam. The vapor of chlorpicrin is almost six times as heavy as air. Chlorpicrin is a respiratory irritant and lachrymator. It is not as poisonous as some of the other gases, but it penetrates masks and respirators more rapidly. It was used with other gases for the reason that it produces nausea and vomiting. This forces the removal of the masks at which time the enemy is overcome by the more poisonous gases which have been fired. It is an active lachrymator and is used to some extent for that purpose. Due to its high boiling point chlorpicrin has been used chiefly in shells mixed with other gases. It was seldom used alone. In its action it stands midway between chlorine and phosgene, being slower in its effects than chlorine but more rapid than phosgene.

CHAPTER II

THE TOXICOLOGY AND PATHOLOGY OF THE LETHAL GASES

The problem submitted to this division was the study of the changes induced by toxic gases in the economy of animals, with special reference to modifications in intermediary metabolism, and the determination of alleviative and curative measures.

It is obvious that in order to interpret intelligently the effects of gas poisoning upon the organism, it is essential to determine the changes, so far as possible, that the gases bring about. Inasmuch as these alterations are generally of a chemical nature the problem must be attacked by chemical methods. The knowledge thus gained is fundamental for any measures that may be employed to prevent or alleviate the detrimental effects of poisonous gases.

In order that consistent results might be obtained considerable attention was given to the experimental method of gassing. The technique as finally evolved was worked out in coöperation with Doctors Barbour and Marshall, the details of which may be found in the Appendix, page 183. In principle it consists of passing a mixture of gas and air through an airtight chamber containing the "experimental animal" for a definite period at a determined rate, checking the mixture by frequent analysis of samples taken from the chamber. Unless otherwise indicated the experimental animal employed throughout this investigation was the dog.

The exposure of the dog to the gases elicits the following reactions, each gas differing slightly from its neighbor. The general clinical symptoms induced by gassing with chlorine are—at first, general excitement as indicated by restlessness, barking, urination, and defecation. Irritation is distinctly visible as seen by the blinking of the eyes, sneezing, copious salivation, retching, and vomiting. Later the animal shows labored respiration with frothing at the mouth. Food is refused although the animal may drink a large quantity of water. The respiratory distress increases until eventually death may occur from apparent asphyxiation. On the other hand, if the concentration of gas is not lethal the animal may present an emaciated appearance and be greatly distressed for several days, followed by ultimate recovery and return to apparently normal conditions.

Phosgene acts chiefly as a respiratory irritant, but is also a lachrymator. Very small doses, scattered in the air, cause coughing, watering of the eyes, and intense dyspnœa. It differs from chlorine in that in these small concentrations its influence is limited mainly to the terminal air cells of the lungs. This effect leads to edema of the lungs, accompanied by interference with the respiratory exchange and consequent cyanosis, a grave condition usually terminating in death. The first symptoms are dizziness and cyanosis on exertion. It usually takes several hours for the serious symptoms to develop, and in the interval there may be no sign of danger.

At high concentrations there is slight lachrymation and uneasiness. The pupil becomes clouded but the animal shows no violent symptoms. Subsequently dogs exposed to high concentrations develop a hard cough, respiration becomes more and more difficult, usually there is a rattling in the throat, and death follows three to twelve hours after exposure.

Animals subjected to lower concentrations develop the same sort of symptoms which are, however, not quite so severe at first. Death occurs after 18 to 36 hours as a rule. After death the nostrils and trachea are filled with mucus. The lungs are collapsed and filled with mucus and blood. The slow filling of trachea and lungs accounts for the deaths which occur 18 to 48 hours after gassing. The heart action grows weaker as death approaches but persists after all attempts at breathing have ceased.

Chlorpicrin is a lachrymatory and respiratory irritant. Repeated exposure is said to cause increased susceptibility. It produces coughing, nausea, and vomiting, and in large quantity may cause unconsciousness. Secondary effects are bronchitis, shortness of breath, a weak irregular heart, and gastritis. It may also cause acute nephritis. Liquid chlorpicrin has a corrosive action on the skin, and scratches and abrasions if exposed to chlorpicrin fumes invariably become septic and abscess formation may result.

During the early part of exposure to chlorpicrin the eyes are irritated at once, and lachrymation occurs. The mucous membrane of the nose and mouth is almost instantly irritated, the animal licking its nose and swallowing frequently. There is always increased nasal secretion and usually salivation, and in cases where salivation cannot be observed the animal may be swallowing the saliva. Usually retching and vomiting take place 10 to 15 minutes after the beginning of the exposure with the higher concentrations. With lower concentrations the animal does not always retch. Toward the end of the exposure the animal is usually depressed, and in some cases marked paleness of the mucous membrane in the mouth is observed. The respiration is usually affected early, being somewhat rapid in the early part of the exposure and becoming slower at the end. A tracheal rattle soon develops and respiration is labored and painful. The animal often has a bad cough, and is generally depressed. Convulsions have been observed just before death. In case of survival the dog has symptoms of bronchitis and rhinitis for a few days, and then is apparently normal.

A comparison of the three gases shows quite plainly that chlorine has a very strong irritating action, the animal becoming excited and in evident distress. With chlorpicrin the character of the reactions produced are very similar to those of chlorine, except that they are less pronounced. Phosgene, on the other hand, appears to cause the animal no immediate distress. Instead of becoming unduly excited the dog lies quietly in the chamber and even when symptoms of poisoning appear hyperexcitability is not present. It would seem that a certain degree of peripheral anæsthesia is present, handling the animal failing to act as a stimulus to muscular activity, struggling, so characteristic with chlorine and chlorpicrin dogs.

PATHOLOGY *

Chlorine

From the pathological aspect chlorine produces injury to the organism by causing immediate death of the epithelium lining the upper respiratory tract. This is shown by the use of vital stains, by means of which a staining reaction, characteristic of dead cells, can be demonstrated immediately after gassing, before it is possible to recognize a fatal injury to a cell by ordinary staining methods. Areas of focal necrosis in the lung itself are also to be attributed to the direct action of chlorine on parts of the lung not protected by bronchiolar spasm.

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* Taken from reports of Doctor M. C. Winternitz.

The destruction of the epithelium of the trachea and bronchi removes the normal protective mechanism of the upper respiratory tract, and allows pathogenic bacteria from the mouth to find their way into the injured bronchioles within a very short period after the epithelium has been destroyed. Bacteriological investigations which show that the pneumococcus and a small Gram-negative hemoglobinophilic organism, normal inhabitants of of the dog's mouth, can be cultivated from the lung as early as one half hour and as late as four days after gassing, give support to the view that the lungs' normal barrier against infection is lost.

The bacterial infection results in a pneumonia, lobar, lobular, or necrotizing, the type depending upon the organism concerned. The pneumonia is associated in all cases with an infection lesion of the bronchi. The infection tends to persist in animals surviving the acute period, resulting in a chronic bronchitis, organizing or obliterative bronchiolitis, with scarring of the lung. Such lesions are demonstrable in dogs dying or killed as late as six months after gassing. The irritating action of chlorine results in a bronchiolar spasm, which, interrupting the normal inflow and outflow of air, causes an acute emphysema or atelectasis, most marked in animals dying in the acute stage.

Edema of the lungs, trachea and bronchi is the most striking feature of acute death from chlorine gassing. It is probably brought about by the direct action of the gas, which so damages the bronchi and alveoli as to render permeable the adjacent capillary wall. The coagulation of the plasma as it passes out through the alveolar wall leads to the deposition of fibrin in this situation, which must seriously interfere with the inflow of blood through the lung, thus putting a strain upon the right side of the heart.

Phosgene

With phosgene gassing the lesions seen at autopsy vary according to the length of time the animal survives after exposure to the gas. At first there is a severe pulmonary edema associated with extreme congestion which reaches a maximum after the first 24 to 36 hours and disappears gradually in animals surviving ten days or longer. The edema is associated with an inflammatory exudation of fibrin and leucocytes, which is most marked in and around the finer bronchioles and which spread to a variable extent through the lung tissue. A typical lobular or pseudo-lobar pneumonia is the result. The pneumonia is frequently complicated by a necrotization of the wall of the bronchus, which may involve the adjacent alveoli to form abscesses. On the other hand, the inflammatory process may be combated successfully, but in an attempt at healing foci of organizing pneumonia and obliterative bronchiolitis result. These constitute chronic foci of infection as shown by bacteriological studies.

The character of the phosgene lesion is explained by the localization of the action of the gas upon the air tubes. The epithelium of the trachea and larger bronchi is not damaged, while that of the smaller bronchi and bronchioles is seriously injured, the more distal portion suffering most. In addition to the changes in the mucosa the bronchi also show pathological contractions and distortions which result in the more or less complete obliteration of their lumina. These in turn lead to mechanical disturbances in the air sacs, resulting in a chronic condition of atelectasis or emphysema.

Chlorpicrin

Chlorpicrin injures the epithelium of the entire respiratory tract, but all portions of the tract are not equally affected. The trachea and largest bronchi though irritated suffer only slight transient injury. The medium sized and small bronchi are the most affected. There is a uniform widespread damage of the alveolar walls which, however, is not severe enough to lead to necrosis. The alveoli are apparently nowhere protected by constriction of the bronchi.

The overwhelming edema of the lungs rapidly follows exposure to the lethal concentration of the gas. In extreme cases practically every alveolus is filled with fluid. In addition to the fluid in the lung itself there is also marked edema of the mediastinal tissues and pleura, which is even more striking than in phosgene and chlorine gassing. The edema fluid contains fibrin and a great deal of fibrin is found in the alveolar walls. It is especially abundant in cases that have succumbed after 24 hours or more. Partial or complete occlusion of the smaller bronchi by inflammatory exudate or masses of necrotic cells leads to focal emphysema or atelectasis, but this is not such a striking feature at autopsy as in the case of death from some of the other respiratory irritant gases, for example, phosgene. Infection of the lungs with the development of a widespread bronchitis and bronchopneumonia is seen in a large percentage of those animals which do not die in the first few hours after gassing. Abscess formation, pleurisy, fibrinous or purulent, and organizing pneumonia are common complications. In recovered animals there is a regeneration of the epithelium of the bronchi and alveoli, and organization of the necrotic bronchiolar wall, with scar formation. Focal atelectatic emphysematous patches remain as prominent gross evidence of the gas injury.

A comparative study of the pathology of chlorpicrin, chlorine and phosgene shows that chlorpicrin in its action on the respiratory tract occupies a position somewhere between chlorine and phosgene. It damages the trachea and larger bronchi less than chlorine, but more than phosgene. In its action on the bronchioles and alveoli it resembles phosgene very closely, but in several other respects the lesions are more like those of chlorine. The gross and microscopic differences in the effects of the three gases on dogs are sufficiently clear cut to enable an experienced observer to determine by autopsy which gas has been used. It should be possible to make practical application of this knowledge on the battlefield in the identification of the gas being used by the enemy.

TOXICITY AND LETHAL CONCENTRATIONS

The method of exposing experimental animals to definite concentrations of the gas has been indicated (see Appendix, page 183). The animals were always gassed singly, experience having demonstrated that when two dogs are gassed at once in the same chamber very inconstant toxicity figures are obtained. This is due to the fact that the gas mixture in the chamber shows very wide variations in composition, probably owing to the difficulty of properly controlling the flowmeter. It is possible that an extensive experience with the flowmeters might obviate this factor. On the other hand, when the dogs are gassed singly the toxicity figures obtained are strikingly constant.

The question of the lethal concentration of the different gases for dogs was next investigated. For this purpose animals were employed which included both sexes, various breeds, ages, and states of nutrition, but in every instance the dogs were considered good subjects for experimentation, none having previously undergone any experimental treatment. In all instances the animals were subjected to the action of the gas for a period of one-half hour, the rate of flow of air through the chamber being 250 liters per minute.

Lethal Concentration of Chlorine

For the investigation with chlorine 112 animals were employed. The results of the study are summarized in Table I, which shows the toxicity of chlorine gas for a one-half hour exposure at various ranges of concentrations, expressed both in milligrams of chlorine per liter of air and in parts of chlorine per million parts of air. The data from this table demonstrate that dogs gassed with high concentrations (2.53 mgm. or above, per liter) of chlorine gas usually die from the acute effects within the first seventy-two hours. The small percentage of animals which survive this acute stage usually recover within a week. The dog gradually develops an appetite and appears normal with the exception of some emaciation and a laryngitis or bronchitis, either of which may persist for some time.

At lower concentrations (1.90–2.53 mgm. per liter) the percentage of recoveries increases rapidly. Another condition stands out prominently at these concentrations, namely, a group of animals which survive for several days. The symptoms are loss of appetite, extreme depression, weakness, and rapidly developing emaciation. Death after this chronic condition must be differentiated from the acute deaths, since the former is generally due to secondary factors, usually a pneumonia of the purulent type. The animals in the chronic condition do not exhibit the acute symptoms, i. e., labored and distressed breathing, after one or two days. Therefore, three days has been arbitrarily chosen as the extreme limit for acute deaths.

TABLE I

Toxicity of Chlorine Gas

Concentration: Mgm. Cl per liter of air—	*0.16–.80*	*1.27–1.58*	*1.58–1.90*	*1.90–2.22*	*2.22–2.53*	*2.53–2.85*	*2.85–6.34*
Parts Cl per million of air—	*50–250*	*400–500*	*500–600*	*600–700*	*700–800*	*800–900*	*900–2000*
Percentage of Deaths							
1st Day				19	17	52	71
2nd Day		6	10	24	22	26	21
3rd Day			10		11	9	
Total Acute Deaths		6	20	43	50	87	92
Delayed Deaths	11	24	20	24	11	4	
Recoveries	89	70	60	33	39	9	7
Survivals	100	94	80	57	50	13	7
Number of animals exposed	9	17	10	21	18	23	14

At still lower concentrations (1.58–1.90 mgm. per liter) the percentage of recoveries increases markedly. The acute symptoms are much less noticeable and recovery takes place much more rapidly than at higher concentrations.

Concentrations above 2.53 must be regarded as lethal.

Concentrations below 1.90 are rarely fatal under the conditions of these studies.

These facts have led to a general classification of gassed animals into three groups: *Acute deaths*, *Delayed deaths*, and *Recoveries.*

(a) *Acute Deaths:* Animals which succumb to the immediate effects of the chlorine gas, namely, deaths directly induced by edema of the lungs. The majority of the deaths from this cause occur within twenty-four hours after gassing but some animals survive for two or three days. However, these animals form a rather clearly defined clinical group, and experience has shown that all animals dying within three days may be classified together as "acute deaths."

(b) *Delayed Deaths:* Animals which survive for more than three days after gassing, but which do not recover. In the majority of cases deaths classed as "delayed" result from secondary factors, chiefly bronchopneumonia following the subsidence of the acute pulmonary edema. This group of deaths, therefore, cannot be ascribed *directly* to the gassing, and thus fall beyond the limits of this investigation.

(c) *Recoveries:* Animals which recover from the gassing with, in some cases, minor secondary symptoms as bronchitis, laryngitis, slight depression or emaciation.

The delayed deaths and recoveries, therefore, together comprise animals which have successfully resisted the *direct* effects of the gas, and may be grouped together as "survivals," that is, survive the acute period. With chlorine this group includes a relatively large number of dogs, whereas with phosgene and chlorpicrin the groups classed as "recoveries" and "survivals" are almost identical.

A study of Table I shows that at concentrations below 0.81 mgm. of chlorine gas per liter of air not a single acute death occurred among the dogs of the series. At concentrations between 1.27 and 1.90 mgm. from 6 to 10 per cent of the animals died acutely, but none before the second day after gassing. Concentrations between 1.90 and 2.22 and between 2.22 and 2.53 mgm. per liter give about 50 per cent acute deaths which are fairly equally divided between the first and second day.

Coming to concentrations above 2.53 mgm. the picture changes abruptly, about 90 per cent of the 20 animals in the series dying acutely and of these the great majority occurred on the first day.

A closer analysis of the data from gassing for one-half hour at concentrations above 2.53 mgm. per liter of air shows that between 2.50 and 2.85 mgm. the proportion of acute deaths is 87 per cent, which is nearly as great as at concentrations between 2.85 and 6.34 mgm. when it reached 93 per cent. In view of this result and the fact that the proportion of acute deaths to recoveries increased rapidly and consistently as the gas concentration was increased up to 2.53 -2.85 mgm., this concentration must be considered as representing essentially the minimum lethal toxicity. The same conclusion is reached when the delayed deaths and recoveries are analyzed separately.

Therefore all the data from the study of over 100 dogs gassed for half an hour at various concentrations between 0.16 and 6.34 mgm. of chlorine gas per liter of air clearly indicate that the minimum lethal toxicity of chlorine gas under the conditions of the experiment is between 2.53 and 2.85 mgm. per liter.

TABLE II

Toxicity of Phosgene Gas

Concentration: *Mgm. Phosgene per liter of air—*	*0.17–.21*	*.22–.26*	*.26–.30*	*.31–.35*	*.35–.39*	*.39–.43*	*.44–.48*	*.48–.55*
Parts Phosgene per million of air—	*41–50*	*51–60*	*61–70*	*71–80*	*81–90*	*91–100*	*101–110*	*111–125*
Percentage of Deaths								
1st Day	8	26	23	36	54	50	70	100
2nd Day	20	13	21	19	14	11	9	
3rd Day	4	8	4	9	2		6	
Total Acute Deaths	32	47	48	64	70	61	85	100
Delayed Deaths	16	10	10	8	9	3	3	
Recoveries	52	44	42	28	21	36	12	
Survivals	68	54	52	36	30	39	15	0
Number of animals exposed	25	39	79	53	56	36	33	6

Lethal Concentration of Phosgene

Figures relative to the toxicity of phosgene may be found in Table II, which is a record of experiments on 327 animals. It will be noted there that the periods of death have been divided into those occurring in one day, two days, and three days, and that these deaths are called the "Total Acute Deaths." Beyond the period of three days death is called "Delayed Death."

The concentrations employed were as follows:—

41–50 parts of phosgene per million of air (0.17–0.21 mgm. per liter)
51–60 parts of phosgene per million of air (0.22–0.26 mgm. per liter)
61–70 parts of phosgene per million of air (0.26–0.30 mgm. per liter)
71–80 parts of phosgene per million of air (0.31–0.35 mgm. per liter)
81–90 parts of phosgene per million of air (0.35–0.39 mgm. per liter)
91–100 parts of phosgene per million of air (0.39–0.43 mgm. per liter)
101–110 parts of phosgene per million of air (0.44–0.48 mgm. per liter)
111–125 parts of phosgene per million of air (0.48–0.55 mgm. per liter)

From the figures given it may be seen that, as a general statement, the higher the concentration of phosgene the more acute is death, and that for the most part death occurs within the first 48 hours. If animals survive beyond the three-day period they stand a very good chance of complete recovery, the delayed deaths not being especially significant.

A point of considerable interest is the fact that the total recoveries at concentrations between 0.31–0.35 and 0.35–0.39 mgm. per liter are about the same, although very acute death, especially within a period of 24 hours, is much more marked at the higher concentration than at the lower. From these results it may be concluded that the minimum lethal concentration of phosgene is 0.31–0.35 mgm. per liter.*

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* The results obtained with the higher concentration, 0.39–0.43 mgm. per liter, are difficult of explanation and apparently are anomalous.

Lethal Concentration of Chlorpicrin

The concentrations of chlorpicrin employed were as follows:—

49–69 parts of chlorpicrin per million of air (0.36–0.50 mgm. per liter)
70–89 parts of chlorpicrin per million of air (0.51–0.65 mgm. per liter)
91–110 parts of chlorpicrin per million of air (0.66–0.80 mgm. per liter)
111–131 parts of chlorpicrin per million of air (0.81–0.95 mgm. per liter)
132–151 parts of chlorpicrin per million of air (0.96–1.10 mgm. per liter)
153–172 parts of chlorpicrin per million of air (1.11–1.25 mgm. per liter)

Table III gives results of observations on 219 dogs. From this table it may be seen that, in general, the higher the concentration of chlorpicrin the more acute is death, particularly the deaths within the first 48 hours. The number of deaths occurring within 24 hours at concentrations 0.96–1.10 and 1.11–1.25 mgm. per liter are about equal. The minimum lethal concentration of chlorpicrin has been taken as 0.81–0.95 mgm. per liter, where 43 per cent of animals receiving this concentration ultimately recovered.

A comparison of the toxicity of the three lethal gases shows that in all acute death is a prominent feature. With chlorpicrin very few animals die a so-called "Delayed Death." With phosgene this feature of delayed death is slightly greater, but not especially prominent. It is quite evident that phosgene is by far the most toxic gas; chlorine being the least poisonous; and chlorpicrin standing between. With respect to the acute effects of the lethal gases, the similarity of the general effects on dogs, as outlined above, and of these gases on men in the field, a striking illustration is afforded by the following paragraph from a captured German medical pamphlet:

"The majority of deaths occur during the first 24 hours and in fact during the first 12 hours, with symptoms of pulmonary edema and failure of the circulation. A diminishing number of cases die on the second and third days with accentuation of the inflammatory symptoms in the lungs. The number of cases that die still later is proportionally very small. A case who has developed no severe symptoms by the third day is seldom endangered. On the other hand, the possibility of a late increase in the gravity of the case cannot be excluded with certainty before the end of the first week."

TABLE III

Toxicity of Chlorpicrin Gas

Concentration: Mgm. Chlorpicrin per liter of air—	*0.36–.50*	*.51–.65*	*.66–.80*	*.81–.95*	*.96–1.10*	*1.11–1.25*
Parts Chlorpicrin per million of air—	*49–69*	*70–89*	*91–110*	*111–131*	*132–151*	*153–172*
Percentage of Deaths						
1st Day	8	9	15	30	55	52
2nd Day		6	9	17	8	29
3rd Day			4	6	2	3
Total Acute Deaths	8	15	28	53	65	84
Delayed Deaths		3		4	2	6
Recoveries	92	82	72	43	33	10
Survivals	92	85	72	47	35	16
Number of animals exposed	12	34	46	47	49	31

CHAPTER III

THE INFLUENCE OF THE GASES UPON RESPIRATION, PULSE AND TEMPERATURE

Respiration

THE immediate effect of phosgene poisoning is to cause an increase in the rate of respiration and from a normal figure of approximately 20, the rate during the first few hours after gassing will be found in most cases to have risen to about double the normal figure—see Figure 1. The data for Figure 1 may be found in the Appendix to Chapter III, page 194.

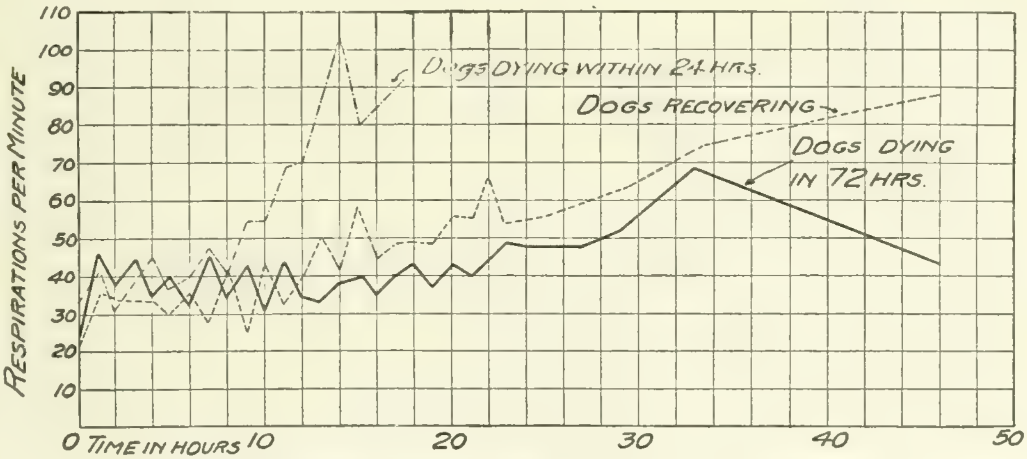

Fig. 1. Respiration in Dogs gassed with Phosgene

In the first few hours following gassing in the animals that are not seriously affected the rate of respiration stays somewhat above normal. In the animals which are seriously affected respiration in general increases in rate but decreases in depth so that there is rapid shallow breathing. This is apparently coupled with the development of edema in the lungs of these animals. The results so far attained from the study of the respiration apparently do not afford a *consistent* index as to the condition of the animal, but a rapid shallow breathing, in many of the cases, indicates a serious condition.

The general effect of phosgene gas on the respiratory tract of the animals is not very irritating, in fact, as has been noted by other investigators, the phosgene in many cases appears to have an anæsthetic effect. The animals lie very quietly unless they are in very bad condition, and very little mucus is given off from the linings of the respiratory tract and in most cases only slight salivation occurs.

The immediate effect of gassing with chlorpicrin is to lower somewhat the normal rate of respiration—see Figure 2. The data for Figure 2 may be found in the Appendix to Chapter III, page 198. Within two to three hours after exposure to the gas the respiration rate regains the normal and in serious cases continues to increase so that within the first few hours a level may be reached which is considerably above the normal. The high rate of respiration may continue for an extended period. The results from the study of the respiration data so far attained do not afford a consistent index of the animal's condition.

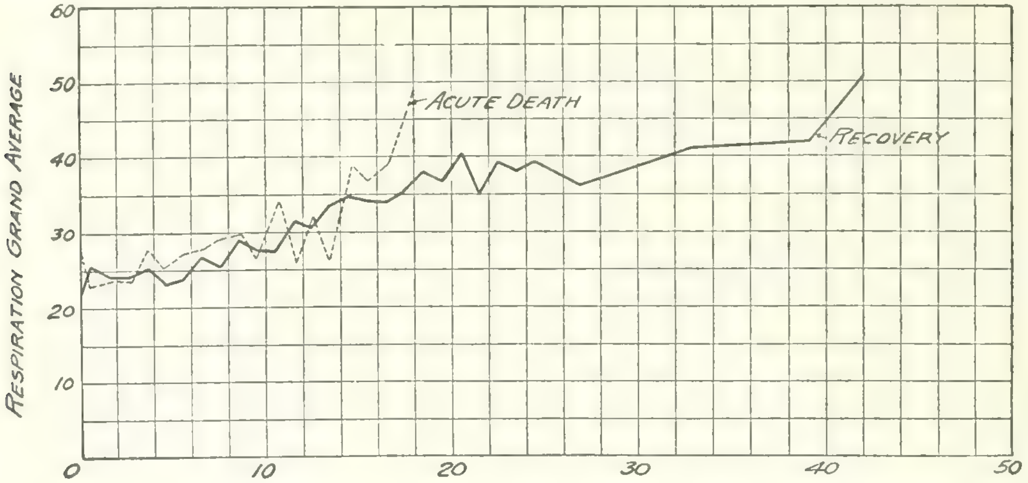

Fig. 2. Respiration in Dogs Gassed with Chlorpicrin

Chlorpicrin is very irritating in its effect upon the respiratory passages and as a result a large amount of mucus and saliva is given off during the first few hours subsequent to gassing. The respiratory passages become more or less clogged and the animal exhibits considerable difficulty in breathing. In many cases the nasal passages are almost completely occluded shortly after exposure to the gas, and the animal breathes through the mouth with a characteristic gasping reflex.

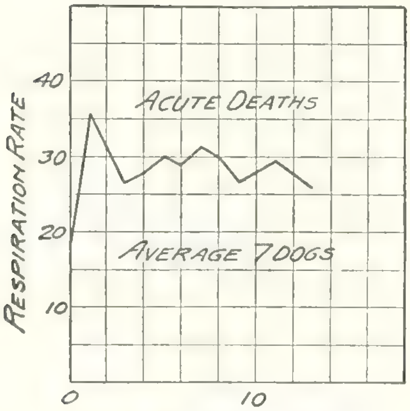

Fig. 3. Dogs Gassed with Chlorine.

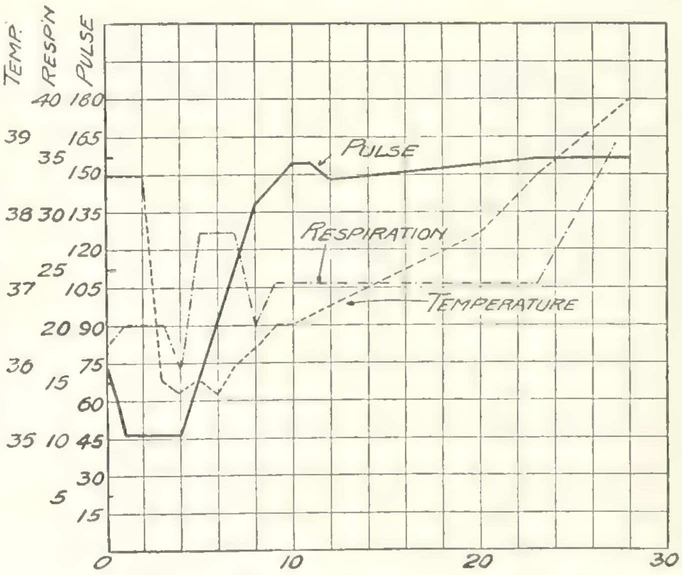

Fig. 4. Recovered Dog-Chlorine Poisoning

Immediately upon exposure to chlorine gas the respiration is markedly accelerated, reaching a high maximum within the first hour—see Figures 3 and 4. The data for these figures may be found in the Appendix to Chapter III, page 208. From this time until the third hour after gassing the rate is decidedly decreased, but is still far above normal where it remains with some fluctuations for the first fifteen hours. At this time most of the animals have died or are about to die. Chlorine is exceedingly irritant to the respiratory passages and almost immediately upon exposure to the gas and for many hours thereafter frothy or stringy saliva drips from the mouth constantly. The quantity of fluid thus lost to the body may be quite large. Respiration is very difficult and apparently the animal has considerable discomfort but does not appear to be in actual pain.

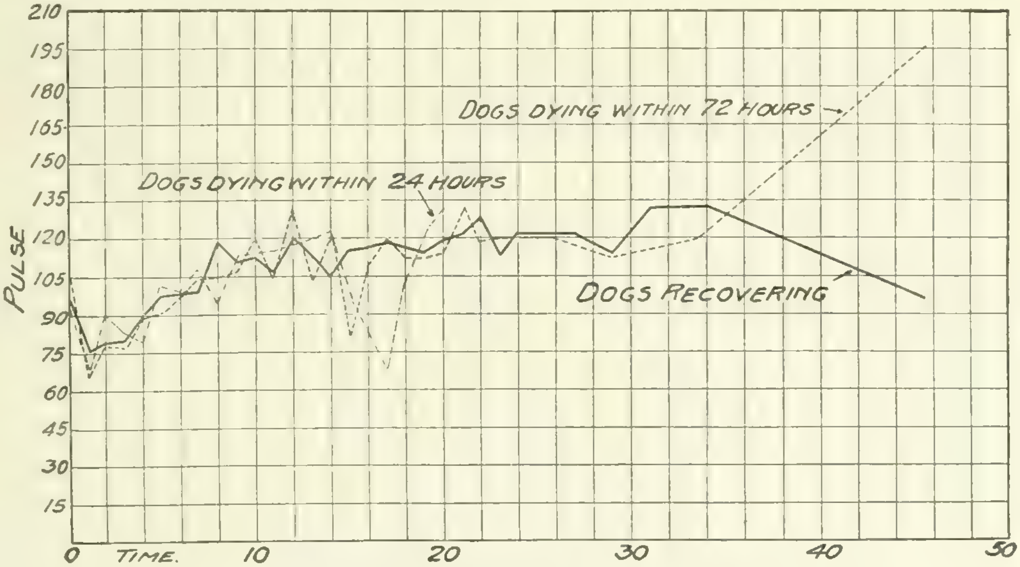

Fig. 5. PULSE IN PHOSGENE DOGS GASSED 40-80

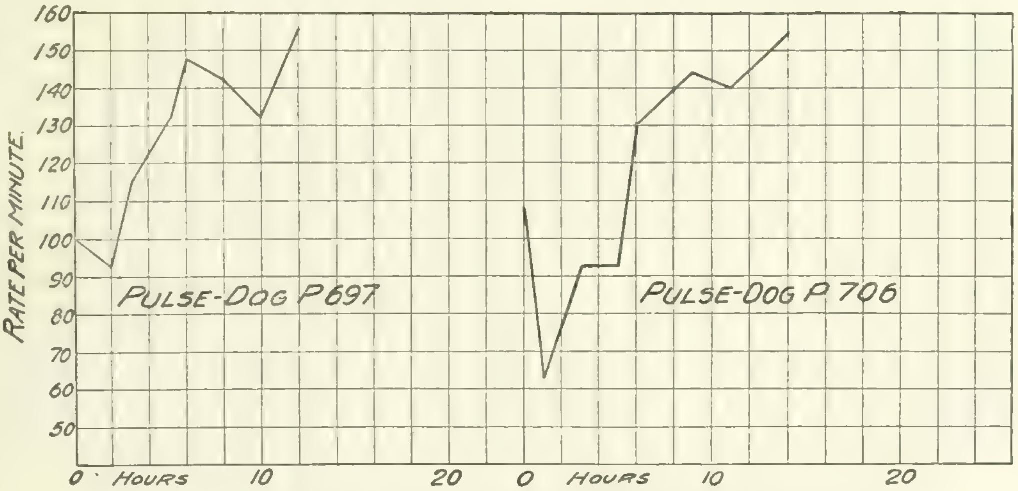

Fig. 6. INDIVIDUAL VARIATIONS IN PULSE RATE OF DOGS GASSED WITH PHOSGENE.

Pulse

The immediate effect of phosgene poisoning is a decided lowering in the pulse rate. From an average normal of approximately 90 it is found that the rate will drop to about 75 beats per minute—see Figures 5 and 6. The data for these figures may be found in the

Appendix to Chapter III, page 210. Many cases can be noted in which the rate is less than this. In general the normal rhythm is not reached until the fourth or fifth hour after gassing. However, in some cases, during the first hour or so after gassing the pulse regains the normal rate. The heart may remain at this rate or slightly higher for some hours and then there may be a gradual increase, occasionally a very rapid increase, and in the course of ten or twelve hours in such cases the heart rate may react close to 150 beats per minute. In the animals which are less seriously affected, the rate in general remains more nearly normal than it does in those which are in a serious condition. The individual observations for the most part show that the worse the animal is affected the higher will be the pulse rate. The pulse rate will continue high until the animal dies. There is evidence in some cases that the high rate of the heart beat results in a circulatory failure. In such cases the pulse rate will drop very rapidly until it reaches a point which may be considerably below normal and the animal will die soon after.

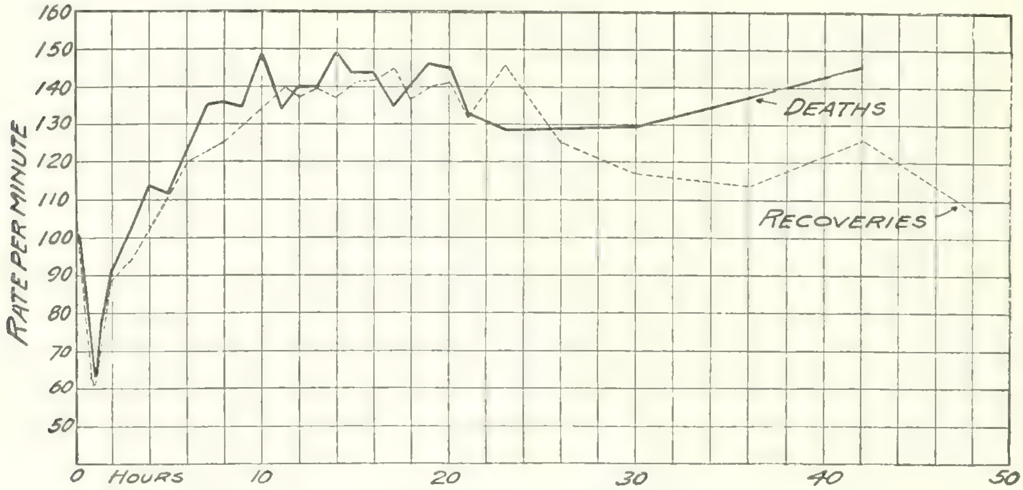

Fig. 7. AVERAGE PULSE RATE OF DOGS GASSED WITH CHLORPICRIN

Gassing with chlorpicrin causes a sharp break in the pulse rate—see Figure 7. The data for this figure may be found in the Appendix to Chapter III, page 214. It may fall to one-half or even less of the normal rate within the first hour. In the hours immediately following, the heart tends to regain its normal beat and in four hours or less the rate in general is normal or above.

In animals that are slightly affected by the gas the heart beat may stay somewhat above the normal figure. In animals that are seriously affected the pulse rate returns to normal very rapidly and then in a few hours may reach a rate of 180–200 beats per minute, which may continue until death. It appears in some cases that the work put on the heart at this period is too great and suddenly the rate will break sharply and the animal will die within a short time.

Immediately subsequent to exposure of an animal to chlorine gas the pulse rate (see Figures 8 and 4. The data for these figures may be found in the Appendix to Chapter III, page 224) falls somewhat and then steadily increases until the rate may reach 150 or more between the sixth and eighth hour. Thereafter the rate falls steadily until it may reach a normal or subnormal value.

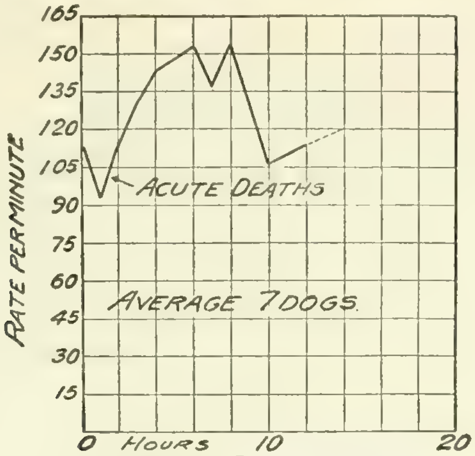

Fig. 8 Pulse Rate in Chlorine Poisoning.

In animals that are not fatally gassed the pulse may fall sharply within the first four hours and then rapidly rise to a very high figure which is maintained for many hours (30 or more).

Temperature

The immediate effect of phosgene poisoning is to cause a break in the temperature—see Figure 9. The data for this figure may be found in the Appendix to Chapter III, page 226.

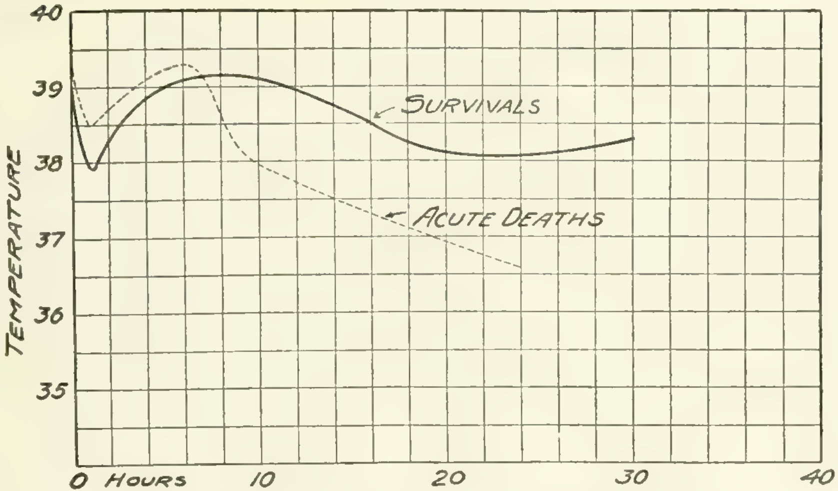

Fig. 9. Temperature Changes in Dogs Gassed with Phosgene.

This is apparently a resultant of the lowered pulse rate and the consequent subnormal circulatory efficiency. This break in the temperature averages about 1° C., so that the normal temperature of approximately 39° C. will fall to 38° C. within one hour after gassing. The average drop is greater in the animals which are not so seriously affected by the gassing. As the pulse rate tends to increase in the hours following gassing, so the temperature of the animal also increases and we find that in the great majority of dogs the temperature has reached normal between the fourth and fifth hours after gassing.

In the animals which are not seriously affected by the gas, the temperature will hover around normal, maybe slightly below or slightly above for the next seven or eight hours, and then begins a slow drop in temperature so that at the end of the first 24 hours after gassing the average temperature of the dogs will be about 38° C. If the animal is withstanding well the effects of the gas the temperature will then slowly begin to rise and in the course of the next 12 hours or so will reach the normal figure again.

In the animals which are seriously affected by the poisoning, the temperature reaches normal more quickly after gassing and instead of hovering around normal tends to go above, and cases have been known in which a temperature of above 40° C. was reached within the first 4 or 5 hours after gassing. The average curves show, however, that a temperature of approximately 39.4° C. will be reached in the seriously affected animals during the sixth hour after gassing. Following this the temperature will begin to break and the more rapidly it falls the more serious will be the condition of the animal. A temperature which has fallen to 38° C. or below in from 9 to 10 hours after gassing indicates the death of the animal within less than 24 hours. The seriously affected animals which survive 24 hours after gassing will show on the average at that time a temperature about 3° C. below normal, or 36° C., and the death of the animal may be expected within less than three days and generally within 36 hours.

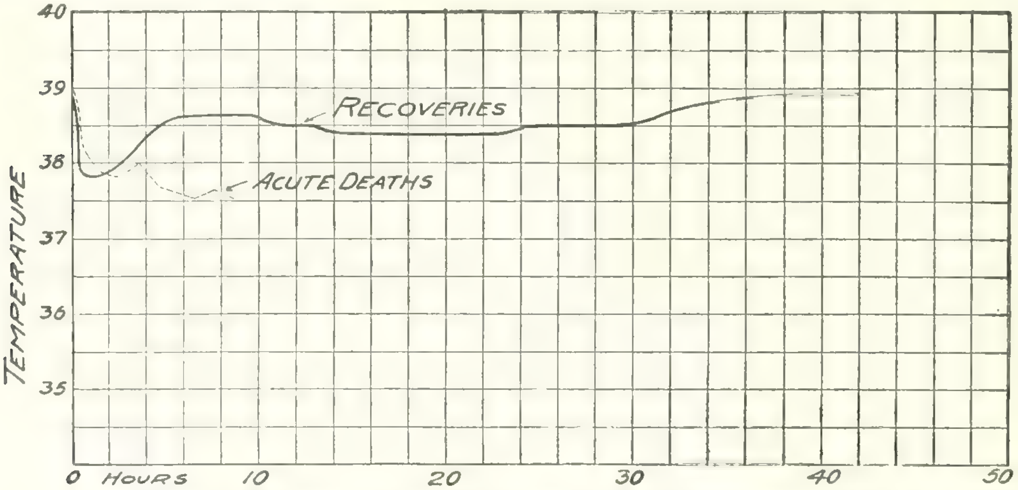

Fig. 10 Temperature Changes in Dogs Gassed with Chlorpicrin.

The temperature of animals after gassing with chlorpicrin shows a drop which in many cases is very marked and may be as much as 2° C. (see Figure 10). The data for Figure 10 may be found in the Appendix to Chapter III, page 230. The average fall is about 1° within one hour after gassing. In the animals that are the most seriously affected the temperature continues to fall, and extreme cases have been noted in which the temperature during the fourth or fifth hour after gassing was 4° C. below normal. In such cases death usually occurs within 12 hours. In the animals that are less affected the temperature after the initial drop within the first hour after gassing will not vary greatly for the next 3 or 4 hours. Beginning at about that period the temperature begins to rise slowly and in exceptional cases may reach normal within 12 hours. However, in most instances the temperature after the fifth hour will begin to break slowly and normal temperature may not be reached for one or two days. The records show that if the temperature during the first 12 hours falls much below 37° C., the animal is in a serious condition.

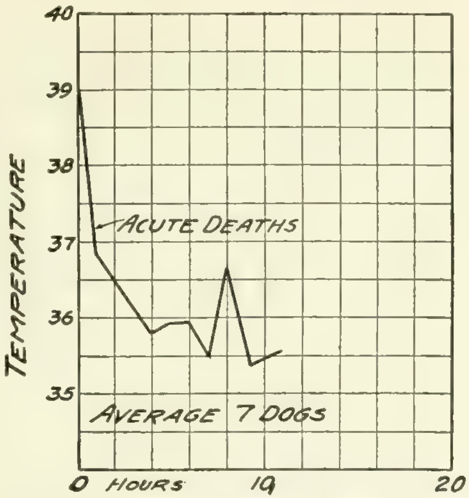

FIG. 11. TEMPERATURE CURVE IN CHLORINE POISONING.

The temperature changes (see Figures 11 and 4. The data for these figures may be found in the Appendix to Chapter III, page 240) of animals after exposure to chlorine gas resemble those of the acute deaths induced by chlorpicrin. With chlorine, however, the tendency is for the temperature to fall even more profoundly than is the case with chlorpicrin just cited. Death usually results in such instances in less than 12 hours from the time of gassing.

In animals less seriously affected there is a similar initial fall in temperature which may, however, gradually return toward the normal, the latter being attained within the first 24 hours.

CHAPTER IV

THE EFFECTS OF REPEATED EXPOSURE TO THE GASES

From a practical viewpoint it is important to know whether an individual becomes more or less susceptible to the gas by repeated exposure. There seems to be a rather widespread opinion that in man a single exposure to a gas greatly increases susceptibility. This view, however, is founded entirely upon general impressions, and in questions of this kind many psychological factors enter which make a clear-cut definition difficult. On the other hand, it is quite plausible to assume that a mucus membrane once extremely irritated might be more easily thrown into an abnormal state by a weaker stimulus than would be true for a membrane which had always been normal. To test this point experiments have been carried through with the chlorine and phosgene gases. No observations were made with chlorpicrin. These animals had all survived an initial gassing for periods of approximately a month at least, and to all appearances were normal.

Of the fifty-three dogs surviving the first gassing with chlorine, eight had received average concentrations under 0.63 mgm. per liter (200 parts per million); six of these were regassed at average concentrations between 2.34 and 2.79 mgm. per liter (738 and 882 parts per million). Nineteen dogs received average concentrations between 1.27 and 1.90 mgm. per liter (400 and 600 parts per million); fifteen of these were regassed at average concentrations between 2.38 and 2.72 mgm. per liter (750 and 860 parts per million). Thirteen dogs received average concentrations between 1.90 and 2.53 mgm. per liter (600 and 800 parts per million); twelve of these were regassed at average concentrations between 2.03 and 3.36 mgm. per liter (643 and 1065 parts per million). Ten dogs received average concentrations between 2.53 and 2.85 mgm. per liter (800 and 900 parts per million); seven of these were regassed at average concentrations between 2.56 and 2.69 mgm. per liter (809 and 851 parts per million). Three dogs received average concentrations above 2.85 mgm. per liter (900 parts per million) and were regassed. (See Table IV.) Table V shows the percentage of deaths and recoveries resulting from these second gassings.

It will be observed that dogs gassed at very low concentrations (column A) show no improvement over the standard toxicity figures; that dogs gassed at medium concentrations at the minimum lethal dose (column B) show a slight improvement; while dogs gassed the first time at high concentrations (columns C and D) show marked improvement. This improvement is found to be proportional to the percentage of deaths resulting after the first gassing at the respective concentrations. This might be interpreted to mean that the first gassing renders an animal less susceptible to a later exposure. On the other hand, it might be argued that in the first gassing only the weaker individuals had succumbed, and that the animals subjected to the second gassing were, therefore, naturally more resistant to the gas. With the latter idea in mind the percentages given above have been recalculated on the basis of the percentage of recoveries from the first gassing, and the deaths resulting from the first gassing are added to the acute deaths from the second gassing. With those recalculated the final percentages are found to be practically identical with the original standard toxicity figures. (See Table VI.)

TABLE IV

Chlorine Regassing

Concentration of first gassing mgm. per liter	*Below 0.63*	*1.27–1.90*	*1.90–2.53*	*2.53–2.85*
Concentration of second gassing mgm. per liter	*2.34–2.78*	*2.38–2.72*	*2.03–3.36*	*2.56–2.69*
1st Day Deaths	4	6	1	1
2nd Day Deaths	1	3	1	1
Total Acute Deaths	5	9	2	2
Delayed Deaths		1	1	
Recoveries	1	5	9	5
Number of dogs	6	15	12	7

TABLE V

Chlorine Regassing

	A	*B*	*C*	*D*
Regassing Figures				
Acute Deaths	83%	60%	17%	29%
Delayed Deaths		7%	8%	
Recoveries	17%	33%	75%	71%
Standard Toxicity Figures				
Acute Deaths	71%	71%	62%	87%
Delayed Deaths	7%	7%	12%	4%
Recoveries	22%	22%	24%	9%

If the view given above is correct this would indicate that the apparently beneficial effect of previous gassing at relatively high concentrations is due largely to the elimination of the weaker or more susceptible individuals by the first gassing. At any rate, the results so far as chlorine is concerned fail to show any increased susceptibility. They indicate that susceptible individuals are eliminated by the first gassing in proportion to the concentration at which they are gassed, and that the survivors have every chance of recovery from a second gassing at the same concentration. If, however, the second gassing is at a higher concentration, a proportionately increased percentage may be expected to succumb.

When the problem of regassing with phosgene is investigated one is confronted with an entirely different picture. Table VII shows that the percentages of deaths and recoveries after the second gassing are practically the same as after the first gassing. This might be interpreted to mean that the first gassing had no lasting effect upon the animal, but the data in Table VIII show that the greater the concentration of the first gassing the greater is the percentage of recoveries after the second. However, if the data are treated in the same manner as were the chlorine data by assuming that the recoveries from the second gassing are selected dogs of greater resistance it is observed that the percentages of recoveries from both gassings are distinctly less than the toxicity figures for the first gassing. These data, which are not entirely adequate because of the small number of experiments, indicate that phosgene poisoning increases the susceptibility of the animal to this gas. In this respect phosgene poisoning is different from that induced by chlorine, which produces no increased susceptibility.

The experience gained with the two gases enables one to conclude definitely that exposure to gas does not render an animal more resistant. Whether on the other hand this treatment actually increases the susceptibility is difficult of decision.

TABLE VI

Chlorine Regassing

	A	*B*	*C*	*D*
Recoveries after first gassing	93%	67%	36%	9%
Deaths after first gassing	7%	33%	64%	91%
Acute Deaths after second gassing recalculated on basis of recoveries from first gassing	77%	40%	6%	3%
Total Deaths	84%	73%	70%	94%
Delayed Deaths after second gassing, recalculated		5%	3%	
Recoveries after second gassing, recalculated	*17%*	*22%*	*27%*	6%
Standard Toxicity				
Acute Deaths	71%	71%	62%	87%
Delayed Deaths	7%	7%	12%	4%
Recoveries	*22%*	*22%*	*24%*	9%

TABLE VII

Phosgene Regassing

Regassed dogs arranged according to concentration of second gassing

Concentration of second gassing:					
Mgm. Phosgene per liter of air—	*0.26–.30*	*.31–.35*	*.35–.39*	*.39–.43*	*.44–.48*
Parts Phosgene per million of air—	*61–70*	*71–80*	*81–90*	*91–100*	*101–110*
Percentage of Acute Deaths	50	68	100	75	86
Percentage of Recoveries	*50*	*32*		*25*	*14*
Acute Deaths—Toxicity	48	64	70	61	85
Recoveries—Toxicity	*52*	*36*	*30*	*39*	*15*
Number of dogs	2	25	6	4	7

TABLE VIII

Phosgene Regassing

Dogs regassed at concentration 71–80 * arranged according to concentration of first gassing

Concentration of first gassing:			
Mgm. Phosgene per liter of air—	*0.17–.21*	*.22–.26*	*.26–.30*
Parts Phosgene per million of air—	*41–50*	*51–60*	*61–70*
Percentage of Acute Deaths after second gassing	80	66	57
Percentage of Recoveries after second gassing	20	33	43
Number of dogs	5	12	7

* 71–80 parts per million = 0.31–0.35 mgm. per liter.

TABLE IX

PHOSGENE REGASSING

Arrangement of data in Table VIII on the same basis as the Chlorine regassing data

Concentration:			
Mgm. Phosgene per liter of air—	*0.17–.21*	*.22–.26*	*.26–.30*
Parts Phosgene per million of air—	*41–50*	*51–60*	*61–70*
Percentage of deaths after first gassing	48	56	58
Percentage of deaths after second gassing recalculated on basis of recoveries after first gassing	*42*	*29*	*24*
Total Deaths	90	85	82
Percentage of recoveries after second gassing recalculated on basis of recoveries after first gassing	10	15	18
Toxicity figures at concentration of second gassing—Recoveries	52	*44*	*42*

CHAPTER V

CHANGES IN METABOLISM AS INDICATED BY A STUDY OF THE URINE

A PROBLEM of fundamental importance in the investigation of the physiological action of inspired gas is whether it, or its decomposition products, actually penetrate the body tissues. Are the poisonous effects of the gas due solely to its action upon the lungs or are they also due in part to absorption into the blood stream and distribution to the body tissues as a whole? A study of the urine would perhaps give an indication in the solution of this problem. This would be true especially with chlorine inasmuch as the changes in chloride excretion might yield a decisive answer to the question.

Selected animals were observed during a six-day normal fasting period, during which time they received water but no food. At the end of each 24-hour period, except the first, the urine was collected and analyzed. The urinary picture thus obtained was taken as an index of the normal metabolism of the subject and affords a basis for comparison with the data obtained after gassing. After this initial normal period the dogs were fed for a week and then again starved. On the second day of this fasting period they were subjected to the action of the gas, and the urine was collected at the end of each subsequent 24-hour period. This procedure was continued, as a rule, for five days, if the animal survived. For the methods of urinary analysis see Appendix, page 242.

The *general* effects of *chlorine* poisoning on the composition of the urine are as follows:— The hydrogen ion concentration is increased, and there is a tendency toward augmented titratable acidity. The "organic acid" figure is markedly increased. The excretion of ammonia, total nitrogen, creatine, uric acid, phosphates, and chlorides is greater than in the normal period. On the fourth or fifth day the output of creatine, phosphates and chloride tends to drop below normal. Large urine volumes are frequent and protein is present in the majority of cases. The picture presented is practically the same in all experiments, though the higher concentrations of chlorine yielded more marked effects. Expressed differently, it may be stated that exposure to chlorine gas of varying concentrations causes in the dog a markedly increased protein metabolism. Typical date may be found in Tables X and XI. For greater details see Appendix, page 242.

Relative to the concentration of gas to which an animal is exposed two types of urinary findings are obtained, namely: (1) That with high concentrations of gas; (2) that with low concentrations of gas. In the high concentrations three features stand out prominently:—

1. Increased nitrogen output.
2. Acidosis.
3. Increased chloride elimination.

1. In order to determine whether the increased protein metabolism is a secondary manifestation of a profound disturbance in the carbohydrate metabolism, the glycogen content of the liver was estimated by Pfluger's method. Determinations were made eight hours after gassing. The results were compared with control determinations made on

normal dogs that had fasted for corresponding periods of time. The data, as given in the following table (Table XII), show that the amount of glycogen in the liver is not materially affected by gassing at high concentrations (2.53–2.85 mgm. for half an hour).

TABLE X

THE INFLUENCE OF CHLORINE POISONING UPON THE COMPOSITION OF THE URINE

Dog No. 1

		Urine												
Date	*Body Weight*	*Volume*	*Specific gravity*	P_H	*Titratable acidity*	*"Organic acid"*	*Total nitrogen*	NH_3 *nitrogen*	*Creatinine nitrogen*	*Creatine nitrogen*	*Uric acid nitrogen*	*Phosphates*	*Chlorides*	*Remarks*
1917	*kilos*	*cc.*			*cc.*	*cc.*	*gm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	
						Normal. Before gassing								
July 23		96	1.064	6.9	57		3.25	136	181	0	13	528	900	
“ 24		76	1.029	6.0	31		2.55	131	186	0	12	58	81	
“ 25	16.0	55	1.049	6.0	44		2.84	176	166	0	17	127	53	
“ 26		67	1.043	5.9	65		3.28	202	156	0	15	187	31	
“ 27		66	1.044	6.0	49		3.17	176	152	0	14	142	33	
						After first gassing (1.47 mgm. per liter for ½ hr. Aug. 6)								
Aug. 6	15.6	82	1.072	6.5	84		4.31	163	147	0	22	391	120	
“ 7		93	1.046	6.1	62		4.67	307	152	96	20	214	640	
“ 8		61	1.047	5.9	51		2.28	149	130	39	17	146	635	
“ 9		39	1.063	5.9	61		1.54	75	131	3	14	192	125	
“ 10	16.2	45	1.042	5.9	37		2.10	146	120	4	13	113	58	
“ 11	15.6													
						After second gassing (2.08 mgm. per liter for ½ hr. Aug. 27)								
Aug. 27	16.7	304	1.023	6.3	127		6.00	272	172	141	50	598	165	Protein
“ 28		406	1.016	5.7	74		4.13	298	156	175	58	271	2016	
“ 29		108	1.032	5.6	89		2.93	230	157	48	35	274	150	
“ 30		73	1.043	5.8	80		2.86	196	148	14	31	257	144	
“ 31		58	1.053	5.8	77		2.23	131	139	3	22	247	150	
						Normal. Before third gassing								
Oct. 9	17.0	94	1.044	6.0	94		3.87	188	159	62	25	346	68	
“ 10		101	1.047	6.3	89		3.74	123	159	43	23	372	163	
“ 11		95	1.047	6.1	97		3.47	135	159	68	20	379	343	
“ 12		99	1.042	6.4	86		3.11	116	155	59	18	355	386	
“ 13		82	1 044	6.6	70		2.57	121	154	53	17	387	286	

TABLE X (*Continued*)

Dog No. 1 (*Continued*)

		URINE												
Date	*Body Weight*	*Volume*	*Specific gravity*	P_H	*Titratable acidity*	*"Organic acid"*	*Total nitrogen*	*NH_3 nitrogen*	*Creatinine nitrogen*	*Creatine nitrogen*	*Uric acid nitrogen*	*Phosphates*	*Chlorides*	*Remarks*
1917	*kilos*	*cc.*			*cc.*	*cc.*	*gm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	
After third gassing (2.05 mgm. per liter for ½ hr. Oct. 22)														
Oct. 22	16.0													
" 23		166	1.034	6.6	49		4.40	105	131	90	25	398	160	
" 24		150	1.038	6.2	81		4.71	298	149	202	27	368	858	
" 25		114	1.040	6.1	67		3.47	200	130	102	21	266	1253	
" 26		74	1.050	6.1	67		3.03	84	128	10	22	307	90	
" 27		77	1.041	6.1	64		2.96	153	115	0	17	272	19	
Normal. Before fourth gassing														
Nov. 27		76	1.054	5.6	81	17	2.94	162	143	25	18	319	73	Protein
" 28		91	1.040	5.5	76	3	2.98	163	143	45	17	322	63	"
" 29		71	1.042	5.4	76	12	2.72	136	144	50	14	288	48	"
" 30		65	1.048	5.8	74	18	2.55	62	145	17	14	298	92	"
Dec. 1		79	1.040	5.7	58	10	2.57	102	148	11	16	247	59	
After fourth gassing (2.69 mgm. per liter for ½ hr. Dec. 10)														
Dec. 10	16.8													
" 11		154	1.060	6.4	103	32	7.53	232	181	129	29	723	159	Protein
" 12		418	1.022	5.9	122	39	6.23	503	177	288	29	411	2000	"
" 13		122	1.050	5.7	127	58	5.42	395	148	162	29	344	1200	
" 14		105	1.039	5.5	77	24	3.86	236	139	63	24	228	155	
" 15	15.0	84	1.038	5.4	59	19	3.20	197	139	6	23	199	11	

TABLE XI

The Influence of Chlorine Poisoning upon the Composition of the Urine

Dog No. 27

		Urine												
Date	*Body Weight*	*Volume*	*Specific gravity*	P_H	*Titratable acidity*	*"Organic acid"*	*Total nitrogen*	*NH_3 nitrogen*	*Creatinine nitrogen*	*Creatine nitrogen*	*Uric acid nitrogen*	*Phosphates*	*Chlorides*	*Remarks*
1917	*kilos*	*cc.*			*cc.*	*cc.*	*gm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	
					Normal. Before gassing									
Sept. 10	13.2	261	1.025	6.3	93		3.35	242	138	130	36	317	590	
" 11		95	1.045	6.3	76		3.52	196	134	132	42	333	244	
" 12		101	1.057	6.3	74		3.56	179	130	112	33	358	244	
" 13		99	1.054	6.5	70		3.42	162	120	74	22	376	123	
" 14		89	1.060	6.3	83		3.63	211	121	51	25	374	57	
		After first gassing (0.40 mgm. per liter for 1 hr. Sept. 24)												
Sept. 24	13.6													
" 25		165	1.041	6.5	84		4.68	252	158	186	26	570	1086	
" 26		150	1.034	6.4	95		4.33	416	154	294	25	353	769	
" 27		106	1.043	6.4	77		4.41	195	151	133	22	301	593	
" 28		96	1.042	6.4	74		3.93	172	173	13	20	333	18	
" 29		111	1.035	6.2	76		3.89	223	143	3	18	336	18	
		After second gassing (0.40 mgm. per liter for 1 hr. Oct. 15)												
Oct. 16		122	1.048	6.1	118		5.39	288	155	118	32	511	140	Protein
" 17		144	1.038	6.1	91		5.50	374	152	99	24	341	581	"
" 18				6.2										"
" 19		128	1.042	6.2	88		5.55 5.30*	310	159	62	23	334	70	"
" 22	10.08													
" 25	Died	3:00 P. M.	(Bronchitis).											

* Protein free.

TABLE XII

Chlorine Experiments

Percentage of Glycogen in the Liver

	Normal Dogs	*Dogs gassed early on second day of fasting period*
Killed second day of fasting period	0.24	0.24 (Dog No. 402)
	0.63	0.42 (" No. 401)
Killed third day of fasting period	0.13	0.12 (Dog No. 400)
	0.26	0.36 (" No. 399)
	0.62	

Since the increased elimination of nitrogenous substances is not accompanied by a complete removal of the glycogen in the liver and therefore cannot be attributed to utilization of protein in place of carbohydrates, it is indicative of destructive processes within the tissues. Possibly it is to be associated with autolytic decomposition in the lungs. In harmony with this idea is the fact that the maximum output of nitrogen falls on the second day after gassing, which is synchronous with a crisis in the lung condition.

2. The increased acidity of the urine and the augmented excretion of ammonia, acid phosphates and "organic acid" all indicate acidosis, a condition which is intensified by the disturbance in protein metabolism. That the acidosis is not primarily dependent upon the augmented protein metabolism is indicated by the conditions that obtain in dogs gassed at low concentrations.

3. The chloride picture (see Table XIII) characteristic of severe gassing shows chloride *retention* during the first 24 hours, followed by increased elimination, the maximum output usually falling on the second day.

This condition is intimately associated with the concentration of the blood, the period of retention being synchronous with the period of blood concentration (see page 47) and the subsequent increased excretion occurring when the blood returns to a more dilute condition. The increased chloride output in the urine probably cannot be accepted as evidence of chlorine absorption during gassing.* This is corroborated by the data from the chloride content of the blood and tissues (cf. page 92). Moreover, the urine analyses fail to show any proportionality between the concentration of the gas administered and the chloride increment eliminated in the urine (see Table XIV). This increment appears to be drawn in large part from the chlorides in the tissues.

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* In this connection search was made for free chlorine in the blood and plasma of dogs before and after gassing. The inorganic chlorides were first determined by the method of McLean and Van Slyke. Samples of blood were also ashed with CaO and Na_2CO_3 and the chlorides determined in the fusion mixture. This procedure obviously would convert any free or organically combined chlorine to chloride and permit its determination as such. No significant difference was found between the two sets of analytical results (see Appendix to Chapter V, page 251). Also qualitative examinations of the protein-free filtrate from the plasma or blood for free chlorine, by means of the reaction with KI and starch paste, were equally negative (see Appendix to Chapter V, page 252). If free chlorine occurs in the blood of gassed animals it is in traces too small to admit of detection by the methods employed. It is obvious, therefore, that chlorine in appreciable amounts does not exist in the blood other than as ionized chloride, and accordingly that direct chlorine absorption by the blood is not a significant factor in gas poisoning.

TABLE XIII

CHLORINE EXPERIMENTS

Comparison of Chloride Excretion in Normal and Gassed Dogs

Dog No.	NORMAL						GASSED					
	Volume of Urine			*Cl as NaCl*			*Volume of Urine*			*Cl as NaCl*		
	2nd day	*3rd day*	*4th day*	*2nd day*	*3rd day*	*4th day*	*2nd day*	*3rd day*	*4th day*	*2nd day*	*3rd day*	*4th day*
	cc.	*cc.*	*cc.*	*mgm.*	*mgm.*	*mgm.*	*cc.*	*cc.*	*cc.*	*mgm.*	*mgm.*	*mgm.*
1^{1}*	96	76	55	900	81	53	82	93	61	120	640	635
1^{2}*	—	—	—	—	—	—	304	406	108	165	2016	150
1^{3}	94	101	98	68	163	343	166	150	114	160	858	1253
1^{4}	76	91	71	73	63	48	154	418	122	159	2000	1200
3	38	63	62	50	31	14	84	80	71	56	238	259
19	123	99	88	525	406	393	162	—	—	94	—	—
60	618	388	325	931	1014	413	189	—	—	117	—	—
104	83	82	86	70	296	172	134	218	140	234	572	430
113^{2}	94	84	95	88	22	25	147	400	372	28	373	320
125	108	132	92	69	68	62	212	487	458	72	716	642
137	98	124	108	220	235	425	160	—	—	406	—	—

* Exponent—1st, 2nd, 3rd gassing, in case dog was regassed.

TABLE XIV

CHLORINE EXPERIMENTS

Dog No.	*Gas concentration per liter of air*	*Exposure*	*Chloride output in excess of normal for 3 days after gassing*
	mgm.	*minutes*	*mgm.*
36^{1}	0.40	30	1129
113^{1}	0.55	30	848
1^{1}	1.47	30	361
1^{3}	2.05	30	1458
1^{2}	2.08	30	1279
3^{1}	2.16	30	458
104	2.58	30	645
1^{4}	2.69	30	3175
36^{2}	2.79	30	1418
27^{1}	0.40	60	1368
113^{2}	1.42	60	316
125	1.54	60	1140

Low Concentrations

The urine of dogs gassed at low concentrations exhibits two main features. The increased output of ammonia and phosphates indicates acidosis, although of a milder degree than that found after severe chlorine poisoning. There is no retention of chlorides during the first 24 hours which may be associated with the absence of edema. The disturbances observed here are chiefly of an electrolytic nature.

The natural recovery of gassed dogs appears to be associated with a distinct improvement on the third day, which is accompanied by a decided drop in the excretion and total nitrogen in particular. On the other hand, if the output of ammonia and total nitrogen remains high or increases on the third day it may be regarded as a bad prognosis, since these conditions obtain in dogs that die at this time.

Dogs gassed at a moderate concentration of *phosgene*, 60–70 parts per million of air (0.26–0.31 mgm. per liter), show the following metabolic changes: The nitrogen metabolism is increased during the second 24 hours after gassing, paralleled by a very high excretion of creatine during this period. The chloride output is very high in the first 24 hours, low in the second, and high in the third, gradually returning to normal on the fifth day. The phosphate output is very high during the first 24 hours, then gradually decreases until it reaches the normal value during the latter part of the experimental period. The sum of the daily phosphate excretion during the period is about the same as that of the normal period. Throughout the interval there is no evidence of diuresis, and the hydrogen ion concentration is not affected. The "organic acids" are unchanged and remain practically constant for both the normal and the experimental periods.

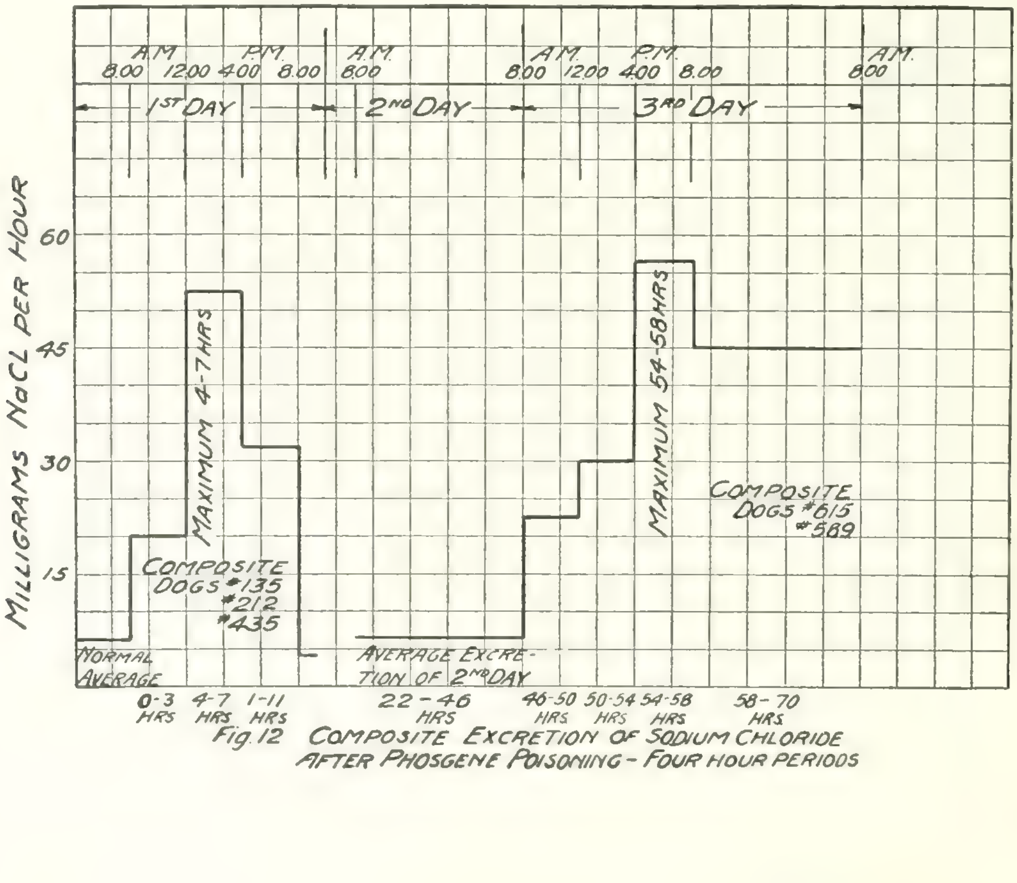

Fig. 12 COMPOSITE EXCRETION OF SODIUM CHLORIDE AFTER PHOSGENE POISONING - FOUR HOUR PERIODS

Dogs gassed at a higher concentration of phosgene, 90–100 parts per million of air (0.40–0.45 mgm. per liter), present a picture similar to those gassed at a moderate concentration, except that the chloride elimination is not as high during the first day. With lower concentrations of phosgene, 40–50 parts per million of air (0.17–0.21 mgm. per liter), the typical changes observed at moderate concentrations are present, although the extent of alterations is less marked.

Tests for various abnormal constituents of the urine give no evidence of a pathological condition. Typical data on the urine may be obtained from Tables XV, XVI, and XVII, and further corroborative results may be found in the Appendix, page 253.

A study of the urine collected at four-hour intervals was carried through in an endeavor to discover at what hours after gassing these changes in urinary output made their appearance (see Tables XVIII, XIX and XX and also Appendix, page 256). The graph of the composite excretion of dogs Nos. 135, 212, and 453 (Fig. 12), shows clearly that the excretion of the chlorides starts to increase immediately after gassing, reaches its maximum in the period between the third and seventh hours, then decreases and returns to the normal level at the eleventh hour. The graph of dogs Nos. 589 and 615 (Fig. 12) shows that the excretion remains at the normal level through the second 24 hours, and begins to increase again after 48 hours after gassing, with a maximum between the fifty-fourth and fifty-eighth hours, after which rise the decrease is gradual in contrast to that in the first 24 hours. The composite graph for the excretion of phosphates (Fig. 13) during the first day shows that the immediate rise after gassing reaches a maximum between the third and seventh hours as did the chloride curve. The decrease, however, from this maximum is more gradual than is true with that of the chlorides.

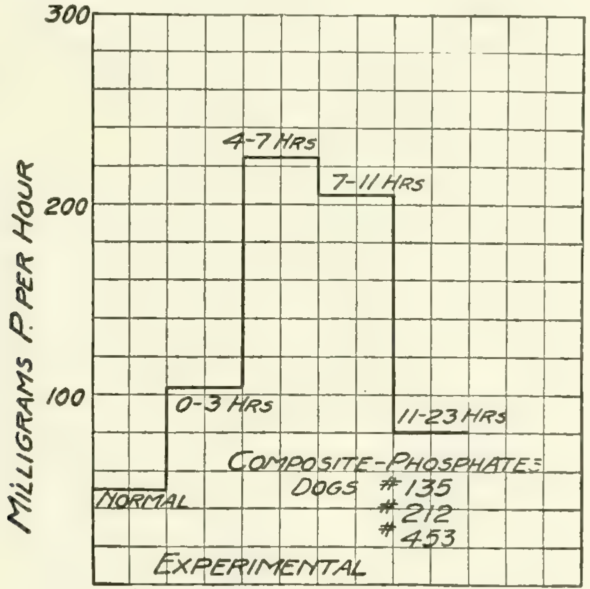

Fig. 13. Composite Excretion of Phosphates after Phosgene Poisoning — Four Hour Periods

TABLE XV

The Influence of Phosgene Poisoning upon the Composition of the Urine

Dog No. 98. Wt. Feb. 18, 14.2 kg.

Date	*Volume*	*Specific gravity*	*PH*	*Titratable acidity*	*"Organic Acid"*	*NH_3 N*	*Total N*	*Creatinine N*	*Creatine N*	*Uric Acid N*	*P*	*NaCl*	*Protein*	*Blood*
1918	*cc.*			*cc.*	*cc.*	*mgm.*	*gm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*		
						Normal								
Feb. 19	135	40	7.2	7	68	100	4.60	150	74	18	261	150	+	Blood
" 20	140	40	6.7	66	42	184	4.77	134	90	16	449	84	+	"
" 21	150	42	5.9	120	26	175	4.90	119	83	16	515	281	—	
" 22	150	34	5.7	124	27	217	4.50	119	59	16	475	139	—	
" 23	115	40	5.7	100	1	178	4.52	117	2	12	414	40	—	
						Gassed. Average Conc. 69 (0.30 mgm. per liter)								
Mar. 5	160	40	6.7	65	16	183	4.55	130	51	23	620	2.41 gm.		Trace
" 6	135	40	5.8	73	25	231	5.60	129	171	31	295	272	—	
" 7	130	38	5.5	78	22	252	4.48	123	112	21	277	840	—	
" 8	110	40	5.4	71	25	155	3.63	109	18	23	278	143	—	
" 9	105	40	5.4	79	9	197	4.12	110	3	18	323		—	
						Regassed. Average Conc. 69 (0.30 mgm. per liter)								
Apr. 30	165	46	7.4+			Very high		101	13	26	550	2.43 gm.		Trace Cystitis
May 1	125	42	6.2	85	15	278	5.42	88	167	21	409	36	—	
" 2	115	50	6.2	103	9	164	6.07	83	162	21	530	224	—	
" 3	115	52	5.9	133	18	204	6.07	77	158	18	520	40	—	
" 4	145	53	6.0	129	8	265	7.23	75	183	18	542	Trace	—	

TABLE XVI

The Influence of Phosgene Poisoning upon the Composition of the Urine

Dog No. 501

Date	*Volume*	*Specific gravity*	P_H	*Titratable acidity*	*"Organic Acid"*	*NH_3 N*	*Total N*	*Creatinine N*	*Creatine N*	*Uric Acid N*	*P*	*NaCl*	*Protein*	*Blood*
1918	*cc.*			*cc.*	*cc.*	*mgm.*	*gm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*		
Normal														
June 6	140	24	7.4+			185	2.03	133	0	8	226	288	+	—
" 7	(Boric acid used)					107	2.44	124	0	8	212	250	+	—
" 8	175	18	6.4	40	17	136	2.59	116	0	12	199	210	Trace	—
" 18	105	30	6.0	50	20	108	3.21	133	13	12	211	124	—	—
Gassed. Average Conc. 44 (0.19 mgm. per liter)														
June 19	135	41	7.4+				3.76	133	119	18	500	728	Trace	—
" 20	160	24	7.4+				3.39	124	202	17	159	120	"	—
" 21	245	18	7.4+				3.15	129	90	18	230	364	"	—

TABLE XVII

The Influence of Phosgene Poisoning upon the Composition of the Urine

Dog No. 264

Date	*Volume*	*Specific gravity*	P_H	*Titratable acidity*	*"Organic Acid"*	*NH_3 N*	*Total N*	*Creatinine N*	*Creatine N*	*Uric Acid N*	*P*	*NaCl*	*Protein*	*Blood*
1918	*cc.*			*cc.*	*cc.*	*mgm.*	*gm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*		
Normal														
May 10	155	40	5.8	77	23	302	5.20	248	0	43	259	1.04 gm.	—	—
" 11	200	36	5.8	105	15	292	5.32	202	0	41	373	434	—	
" 12	165	40	6.2	62	21	177	4.47	200	14	47	395	364	—	
" 13	150(?)	42	6.0	94	11	208	4.52	194	0	46	400	266	—	
" 21	115	42	6.2	91	30	176	4.37	200	0	22	381	210	—	
Regassed. Average Conc. 99 (0.43 mgm. per liter)														
May 22	140	36	6.2	167	33	317	5.80	177	7	42	695	328	—	—
" 23	145	33	6.2	90	31	441	7.65	173	240	50	432	Trace	—	—
" 24	145	48	6.2	62	34	165	6.10	175	279	44	322	40	—	—
" 25	110	46	5.9	90	34	238	4.21	168	30	33	308	496	—	—

TABLE XVIII

THE INFLUENCE OF PHOSGENE POISONING UPON THE COMPOSITION OF THE URINE "FOUR HOUR EXPERIMENTS"

Dog No. 135 Wt. 16 kg.

Date	*Volume*	*Specific gravity*	*P$_H$*	*Titratable acidity*	*"Organic Acid"*	*NH$_3$ N*	*Total N*	*Creatinine N*	*Creatine N*	*Uric Acid N*	*P*	*NaCl*	*Protein*	*Blood*
1918	*cc.*			*cc.*	*cc.*	*mgm.*	*gm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*		
						Normal								
Mar. 26	110	48	5.8	86	30	126	4.25	140	10	21	346	Trace	+	Blood
" 27	100	52	5.5	97	19	165	3.92	130	16	23	380	10	—	
" 28	105	54	5.5	106	16	172	4.03	131	10	23	405	37	—	

Gassed 10:40 A. M. Average Conc. 65 (0.28 mgm. per liter)

	HOUR CATHETERIZED	VOLUME	P$_H$	Total N	Creatinine N	Creatine N	Uric Acid N	P	NaCl
Apr. 1	1 P. M.	19		0.81	34	2	8	84	78
	5 "	29		1.12	30	3	10	281	196
	9 "	31		1.18	29	6	11	250	159
" 2	9 A. M.	60	6.0	2.92	67	10	30	288	24
	Total per day	139		6.03	160	21	59	903	457
	1 P. M.	27		1.35	20	10	15	7	9.5
	5 "	29	6.2	1.29	19	21	13	6	8.4
	9 "	25	6.0	1.27	19	33	15	8	9.5

TABLE XIX

THE INFLUENCE OF PHOSGENE POISONING UPON THE COMPOSITION OF THE URINE "FOUR HOUR EXPERIMENTS"

Dog No. 453

Date	*Volume*	*Specific gravity*	*P$_H$*	*Titratable acidity*	*"Organic Acid"*	*NH$_3$ N*	*Total N*	*Creatinine N*	*Creatine N*	*Uric Acid N*	*P*	*NaCl*	*Protein*	*Blood*
1918	*cc.*			*cc.*	*cc.*	*mgm.*	*gm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*		
						Normal								
May 27	150	24	5.9	51	32	160	3.42	174	12	20	173	204	—	—
" 28	190	20	6.1	61	43	167	3.62	186	33	16	234	370	+	—
" 29	340	8	6.0	47	44	168	3.95	194	101	18	153	180	+	—

	Hour Catheterized	Volume	P_H						
June 10	12:00 M.	335	6.8	.92	35	4	4.7	28	48
	4:00 P. M.	180	6.5	.74	35	4	4.8	18	41
	8:00 "	375	6.0	2.81	133	30	19.7	209	232
	Total	890		4.47	203	38	29.2	254	321
" 11	12:00 M.	50	6.2		33	10	7.1	155	96
	4:00 P. M.	80	6.4	1.11	31	19	9.9	277	222
	8:00 "	50	6.4	.98	33	28	10.3	186	22
" 12	8:00 A. M.	70	6.0	1.67	66	—	23.5	253	—
	Total	250			163		50.8	871	340

Gassed June 11 9:00 A.M. Average Conc. 67 (0.29 mgm. per liter)

TABLE XX

The Influence of Phosgene Poisoning upon the Composition of the Urine "Four Hour Experiments"

Dog No. 589

Date	Hour Catheterized	Volume	P_H	Total N	Creatinine N	Creatine N	Uric Acid N	P	NaCl
1918				*gm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*
	Gassed June 24, 10:30 A. M.			Average Conc. 60 (0.26 mgm. per liter)					
June 25	12:00 M.	20	5.9	.93	30	66	8.2	14.2	12
	4:00 P. M.	48	5.9	1.07	30	56	8.1	19.9	14
	8:00 "	68	6.0	1.15	30	56	9.0	39.0	8
" 26	8:00 A. M.	365	5.9	3.77	92	208	28.0	22.7	50
	Total	501		6.92	182	386	53.3	95.8	84
	12:00 M.	95	5.8	1.03	27	66	11.1	52.5	85
	4:00 P. M.	145	6.2	1.06	28	59	12.5	85.0	139
	8:00 "	105	6.2	.95	28	40	11.1	81.5	243
" 27	8:00 A. M.	185	5.9	2.66	87	85	31.7	17.6	690
	Total	530		5.70	170	250	66.4	236.6	1157
	12:00 M.	265		.94	30	15	8.8	63.0	207
	4:00 P. M.	230		.79	26	10	8.1	75.0	108
	8:00 "	90		1.16	30	35	10.0	70.0	27
" 28	8:00 A. M.	660		2.20	90	7	19.3	190.0	359
	Total	1245		5.09	176	67	47.2	398.0	701

The time for the appearance of the creatine is less definite. The appearance is apparently gradual and may reappear at any time in the second 24 hours.

The increased chlorides of the first day can be associated with the development of edema of the lungs. There is no indication of acidosis in any of the dogs and thus the phosphates are probably not increased for the regulation of any acidity that may have developed. The increase in nitrogen metabolism during the second day may perhaps be due to increased destruction of tissue, that is, lung tissue. The changes in the urinary elimination cannot be explained by altered kidney function, since kidney efficiency tests show these organs to be efficient. (See Appendix, page 258).

With *chlorpicrin* the nitrogen metabolism is increased on the second day, although in some cases it begins to increase on the first day, resulting in an augmented output of total nitrogen, ammonia nitrogen, uric acid nitrogen, and creatine nitrogen. Chloride output is seldom above the normal figure. This is especially true in dogs moderately gassed. (See Table XXI.)

The phosphate elimination is increased greatly during the first 24 hours, often being double the normal figure. In most dogs that die within a day or two after gassing the phosphate output during the first 24 hours is only slightly above normal, and when this is found to be the case it is quite certain the animal will not survive. The titratable acidity between P_H 4.9 and P_H 7.4 runs parallel with the phosphate output, showing that this is a simple titration of the "buffer" reaction of the phosphates.

The volume of the urine, hydrogen ion concentration, and "organic acids" show little or no change as a result of gassing.

TABLE XXI

The Influence of Chlorpicrin Poisoning upon the Composition of the Urine

Dog No. 94

Date	*Volume*	*Specific gravity*	P_H	*Titratable acidity*	*"Organic Acid"*	NH_3 N	*Total* N	*Creatinine* N	*Creatine* N	*Uric Acid* N	P	*NaCl*	*Protein*	*Blood*
1918	*cc.*			*cc.*	*cc.*	*mgm.*	*gm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*		
							Normal							
July 23	145	27	6.1	79	17	69	4.12	179	0	10	382	120	—	—
" 24	360	18	5.9	89	32	101	4.28	152	0	12	335	104	—	—
" 25	255	15	5.8	92	23	92	4.37	154	0	14	364	60	—	—
" 26	275	19	5.8	101	50	111	4.23	150	2	15	347	270	+	Trace
" 27	260	12	5.8	76	17	104	?	146	3	13	324	70	—	—
Sept. 10	230	30	5.5	175	60	347	5.49	116	114	40	488	640*		
Gassed Sept. 10, 9:00–9:30 A. M. Conc. 97 (0.70 mgm. per liter). Wt. 13.2 kg.														
Sept. 11	105	60	5.9	155	16	282	4.22	114	148	71	795	664	—	
" 12	110	42	5.9	82	53	244	4.33	106	160	52	342	480	—	
" 13				Sample lost										
" 14			5.8	71	24	202	2.98	112	44	37	342	390	—	
Dog No. 95							Normal							
July 23	90	41	6.0	60	13	57	3.64	133	8	10	320	150	—	—
" 24	90	49	5.9	104	27	61	3.89	127	0	12	378	162	—	—
" 25	(50?)	24	5.7	90	20	106	4.25	113	0	15	343	172	—	—
" 26	100	50	5.6	120	23	102	4.06	105	0	14	425	830	—	—
" 27	80	46	5.7	90	17	102	3.49	105	3	14	326	200	—	—
Sept. 10	240	28	5.7	174	34	372	5.06	102	51	33	668	660*	—	—

* Diet

TABLE XXI (*Continued*)

Date	*Volume*	*Specific gravity*	P_H	*Titratable acidity*	*"Organic Acid"*	NH_3 *N*	*Total N*	*Creatinine N*	*Creatine N*	*Uric Acid N*	*P*	*NaCl*	*Protein*	*Blood*
1918	*cc.*			*cc.*	*cc.*	*mgm.*	*gm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*		
Gassed Sept. 10, 9:30–10:00 A. M. Conc. 103 (0.75 mgm. per liter). Wt. 9.6 kg.														
Sept. 11	135	60	6.0	172	32	290	5.55	92	153	71	864	550	+	—
“ 12	135	48	6.2	88	32	176	5.63	85	181	45	460	296	—	—
“ 13	175	35	5.9	82	30	314	5.65	81	152	31	365	180	—	—
“ 14	145	48	6.0	107	44	204	5.55	78	136	30	484	236	—	—
Dog No. 133 Normal														
Oct. 4	50	44	5.8	35	13	118	2.05	67	4	11	159	Trace		
“ 5	45	38	5.8	45	15	136	1.92	67	4	10	178	“		
“ 10	45	32	6.0	30	11	90	1.51	66	1	12	142	190		
“ 12	50	38	5.9	45	10	104	1.60	65	4	7	202	190		
“ 17	45	40	5.8	35	11	106	1.40	67	3	12	147	150		
Gassed Oct. 21, 9:40–10:00 A. M. Conc. 123 (0.89 mgm. per liter). Wt. 6.8 kg.														
Oct. 22	95	44	6.9	37	26	168	3.88	67	88	30	396	100	+	
“ 23	180		5.4?	138	29	279	4.78	65	138	30	413	560	—	
“ 24	115	38	6.1	80	19	334	4.95	56	110	25	323	40	—	
“ 25	100		6.0	51	7	228	3.92	58	52	31	240	20	-	
“ 26	70	37	5.9	51	4	132	2.51	50	7	12	223	Trace	—	
Dog No. 165 Normal														
Sept. 24	315	25	5.7	96	88	213	5.88	111	108	17	588	400	—	
“ 25	125	35	6.1	74	29	216	3.67	100	64	19	365	80	—	
“ 26	140	40	5.8	119	63	347	5.07	92	77	21	417	200	—	
“ 27	220	27	6.0	133	40	416	6.55	96	96	24	548	280	—	
“ 28	300	32	5.9	172	39	456	7.65	95	107	29	735	280	—	
Gassed Oct. 7, 9:00–9:30 A. M. Conc. 116 (0.84 mgm. per liter). Wt. 9.7 kg.														
Oct. 8	190	50	6.1	165	7	392	8.50	83	171	34	953	280	—	
“ 9	325	42	6.1	239	37	615	12.50	70	223	40	1062	440	—	
“ 10	385	42	6.0	293	46	575	15.30	55	240	52	1250	560	—	
“ 11	375	46	6.2	260	46	538	16.25	53	334	48	1140	620	—	
“ 12			6.0	212	59	451	13.95	45	373	26	882	450	—	

TABLE XXI (*Continued*)

Dog No. 135

Date	*Volume*	*Specific gravity*	P_H	*Titratable acidity*	*"Organic Acid"*	*NH_3 N*	*Total N*	*Creatinine N*	*Creatine N*	*Uric Acid N*	*P*	*NaCl*	*Protein*	*Blood*
1918	*cc.*			*cc.*	*cc.*	*mgm.*	*gm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*		
Normal														
Sept. 17	40	55	5.3	46	17	80	1.78	60	15	22	166	60		
" 18	50	50	5.4	47	21	98	1.73	54	11	19	149	Trace		
" 19	40	42	5.5	36	8	92	1.50	53	19	17	140	"		
" 20	35	52	5.5	51	19	88	1.59	51	13	18	176	"		
" 21	40	52	5.5			84		52	28	26	176	75		
Gassed Sept. 30, 8:40–10:10 A. M. Conc. 111 (0.81 mgm. per liter). Wt. 5.5 kg.														
Oct. 1	45	54	5.8	60	14	118	1.76				280	50		
" 2	45	40	7.4+								109	300		
" 3	50	32	7.4+		Cystitis						116	75		
" 4	85	21	7.4+								147	40		

Gassings at a low concentration show, in general, the same picture as those of a moderate concentration, except that the changes are less marked. Generally the chloride output is a little higher. (See Table XXII.) Gassings at a high concentration show a picture similar to that at a moderate concentration, but the effects are somewhat prolonged. (See Table XXIII.)

Typical data relative to the influence of chlorpicrin upon the urinary secretion may be found in Tables XXI, XXII, XXIII, further data being recorded in the Appendix, page Kidney efficiency tests were run on some dogs inasmuch as it has been asserted that chlorpicrin may injure the kidneys. In the cases tested no decreased renal function could be detected (see Appendix, page 261).

A comparison of the excretion under the influence of the three gases shows that in all three instances nitrogenous metabolism is definitely increased, the various partitions of nitrogen running more or less parallel curves. In certain instances the increased output is most evident on the first day subsequent to gassing, in other cases the second day shows the greatest excretion. Chloride elimination may be very markedly increased as in the case of chlorine gassing, or only of slight significance as with chlorpicrin, or again it may assume a widely divergent curve as with phosgene. Chloride excretion is undoubtedly linked with the changes in the development of edema, and the chloride output will, therefore, be discussed more fully in the Chapter on The Development of Edema.

Acidosis may or may not be present as indicated by changes in the hydrogen ion concentration, titratable acidity, and "organic acid" figures. These results make it evident that there is, therefore, no essential relationship between the increased nitrogen output and caidosis.

Creatine excretion is quite prominent but seems to follow no definite course. Apparently it is not associated with lack of carbohydrates * as for example with chlorine poisoning, nor can its appearance in the urine be ascribed to a condition of acidosis † since in neither phosgene nor chlorpicrin poisoning is there any indication of such a state. It is possible, however, that it may be due to tissue changes induced in the lungs whereby disintegration occurs with the formation and subsequent elimination of creatine. By such a process both creatine excretion and increased nitrogenous metabolism may be explained, although it must be admitted that the reactions involved are by no means clear. It is quite significant that a second exposure to a gas renders an animal neither more or less susceptible as judged by the influence upon nitrogenous metabolism. So far as investigated there is little evidence that the lethal gases, employing chlorine as an example, are absorbed into the blood stream. At most only the merest traces are absorbed. The damage to the organism is therefore localized upon the respiratory tract.

TABLE XXII

The Influence of Chlorpicrin Poisoning upon the Composition of the Urine

Dog No. 170

Date	*Volume*	*Specific gravity*	P_H	*Titratable acidity*	*"Organic Acid"*	NH_3 *N*	*Total N*	*Creatinine N*	*Creatine N*	*Uric Acid N*	*P*	*NaCl*	*Protein*
1918	*cc.*			*cc.*	*cc.*	*mgm.*	*gm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	
Normal													
Oct. 15	30	48	5.8	30	6	88	1.42	42	5	9	133	60	—
“ 16	45	48	5.7	40	7	135	1.92	56	6	13	176	50	—
“ 17	45	36	5.9	35	6	132	1.86	46	7	11	155	40	—
“ 18	65	32	5.9	42	11	151	1.14	54	13	14	169	30	—
“ 19	50	40	5.9	50	13	146	2.07	54	10	12	180	10	—
Gassed Oct. 28, 9:00–9:30 A. M. Conc. 81 (0.59 mgm. per liter)													
Oct. 29	60	45	6.1	66	10	177	2.88	53	43	18	308	140	+
“ 30	170	19	6.4	44	28	322	3.38	52	140	20	256	700	—
“ 31	120	18	6.0	47	17	178	2.48	49	69	14	171	340	—
Nov. 1	170	17	6.0	36	10	110	1.84	43	16	12	147	20	—
Dog No. 229 Normal													
Oct. 15	135	38	6.5	45	55	357	4.52	122	57	27	332	340	—
“ 16	95	40	7.3	0	83	512	4.00	122	95	18	375	90	—
“ 17			7.3	0	63	448	3.59	111	92	19	363	320	—
“ 18	110	38	7.3	0	49	375	3.14	113	69	18	392	300	—
“ 19	170	26	7.3	0	81	503	3.57	106	51	18	356	390	—

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* Mendel & Rose. J. Biol. chem. 1911–12, X, 213.

† Underhill. J. Biol. chem. 1916, XXVII, 127.

TABLE XXII (*Continued*)

Date	*Volume*	*Specific gravity*	P_H	*Titratable acidity*	*"Organic Acid"*	NH_3 N	*Total* N	*Creatinine* N	*Creatine* N	*Uric Acid* N	*P*	*NaCl*	*Protein*
1918	*cc.*			*cc.*	*cc.*	*mgm.*	*gm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	
Gassed Oct. 28, 9:40–10:00 A. M. Conc. 69 (0.50 mgm. per liter)													
Oct. 29	240	27	6.9	17	52	183	4.75	119	129	27	530	790	
" 30	110	35	6.1	87	24	252	4.40	112	183	23	327	110	—
" 31	190	17	6.0	85	24	230	3.85	96	94	16	290	100	—
Dog No. 230 Normal													
Oct. 15			5.8	37	13	160	1.87	65	38	8	159	130	—
" 16	70	26	5.9	37	12	150	1.72	67	34	6	162	160	—
" 17	55	34	6.0	37	10	129	1.68	64	25	6	166	80	—
" 18	55	30	6.0	44	5	132	1.60	58	24	7	207	130	—
" 19	65	24	6.0	45	15	171	1.77	55	26	6	180	150	—
Gassed Oct. 28, 10:20–10:50 A. M. Conc. 69 (0.50 mgm. per liter)													
Oct. 29			7.0	14	31	137	2.30	58	57	23	209	660	+
" 30	80	32	7.2	4	29	245	2.42	58	124	12	204	110	—
" 31	170	10	6.7	14	24	192	1.94	53	75	9	142	290	—
Nov. 1	95	13	6.4	34	20	112	1.50	52	21	7	145	80	—
Normal Dog No. 269													
Oct. 22	120	34	5.9	77	34	293	3.86	125	20	24	263	320	—
" 23	210	20	6.0	70	31	305	4.05	125	36	22	266	300	?
" 24	230	18	6.2	68	32	264	3.81	125	44	22	280	220	—
" 25	110		5.9	87	34	290	3.40	117	24	26	322	100	—
" 26	150	24	6.0	80	23	282	3.64	110	30	17	298	80	—
Gassed Nov. 4, 10:00–10:30 A. M. Conc. 81 (0.59 mgm. per liter)													
Nov. 5	85	57	6.2	127	17	177	3.89	99	78	28	574	70	
" 6	115	43	6.2	90	34	269	4.85	102	219	29	398	60	
" 7			6.2	82	27	265	4.25	77	107	16	314	120	

TABLE XXIII

The Influence of Chlorpicrin Poisoning upon the Composition of the Urine

Dog No. 96

Date	Volume	Specific gravity	P_H	Titratable acidity	"Organic Acid"	NH_3 N	Total N	Creatinine N	Creatine N	Uric Acid N	P	NaCl
1918	*cc.*			*cc.*	*cc.*	*mgm.*	*gm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*
Normal												
Sept. 10	135	40	5.8	131	54	428	6.15	194	88	50	484	44
" 11	125	40	5.7	106	48	400	5.73	214	91	46	368	40
" 12	130	40	5.6	140	59	390	5.54	233	22	54	432	20
" 13	145	42	5.6	147	95	377	6.00	219	36	55	337	20
Gassed Sept. 23, 9:20–9:50 A. M. Conc. 139 (1.01 mgm. per liter). Wt. 16.5 kg.												
Sept. 24	110	58	5.6	210	61	358	6.74	141	33	83	755	35
" 25	180	50	5.9	72	70	301	7.88	149	335	77	330	40
" 26	150	45	7.2	Cystitis			5.80	135	165	(?)62	375	40
" 27	130	44	7.4				4.79	133	26		301	Trace
" 28				Feces in urine—diarrhea								

Normal

Dog No. 320

Date	Volume	Specific gravity	P_H	Titratable acidity	"Organic Acid"	NH_3 N	Total N	Creatinine N	Creatine N	Uric Acid N	P	NaCl
Nov. 5	125	21	5.8	75	31	241		148	32	23	223	370
" 6	80	29	6.0	55	27	146	3.01	129	78	23	166	300
" 7	100	30	6.0	83	29	185	3.08	126	85	24	270	200
" 8	110	35	6.2	88	20	153	3.22	135	76	33	340	190
" 9	115	30	6.1	85	36	147	3.30	131	37	18	295	200
Gassed Nov. 26, 10:15–10:45 A. M. Conc. 140 (1.02 mgm. per liter)												
Nov. 27	120	42	6.2	112	27	132	5.30	130	135	38	515	136
" 28	195	40	6.1	120	47	234	8.20	112	353	38	474	120
" 29	140	45	6.2	60	34	147	5.24	104	288	39	400	340
" 30	85	38	6.1	62	36	210	4.62	121	165	37	248	80
			Recovered									

CHAPTER VI

Alterations in Blood Concentration

Even a slight experience with gas poisoning leads to the recognition that changes in blood concentration must occur. The evidences for such an impression are not prominent in the early stages, but as time passes it becomes quite apparent that the blood assumes a sticky, concentrated consistency, attempts to draw blood from a vein, for example, being attained with great difficulty. The character of the blood at this period must exert a definite detrimental influence upon the rate of circulation, reacting in time to impede the heart action, and later even to interfere with the proper blood supply to the tissues. Under these conditions the tissues consequently suffer, and normal metabolism has therefore undoubtedly distinctly altered.

The changes in blood concentration have been studied extensively in this investigation, since it has been assumed that such alterations are quite sufficient to explain many of the phenomena associated with gas poisoning. From the fact that observations have been made most intensively with phosgene, the results obtained with this gas will be presented first. In Tables XXIV and XXV may be found data relative to changes in the concentration of the blood subsequent to exposure to phosgene gas of various concentrations. These figures are expressed as percentage changes from the normal for the reason of the wide individual variations among dogs. The original data, however, may be found in the Appendix, Chapter VI, page 264.

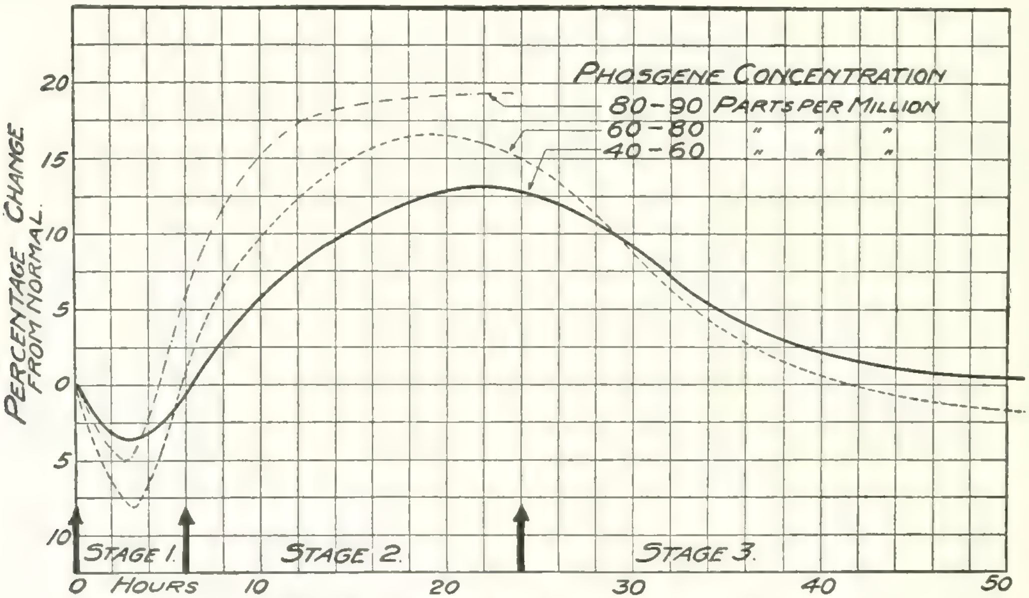

Fig. 14. Changes in Total Solids of Blood after Phosgene Gassing.

An inspection of these tables shows that at first the blood usually contains less solid matter than normally. This condition is maintained for several hours (Stage 1). Later concentration begins and rapidly assumes a maximum (Stage 2), after which there is a gradual return (Stage 3) to the normal level. The relationship is seen most clearly perhaps when expressed graphically. (See Figure 14.)

The results show very characteristic differences between the three gas concentrations selected. At 80 parts per million and above there is a very rapid recovery from the preliminary dilution, the normal being regained within 4 to 5 hours. The succeeding concentration is correspondingly rapid, reaching a maximum at 12 to 14 hours and is at a level 18 to 20 per cent above the normal. Practically all of these dogs died during the second stage so that Stage 3 is not represented at this concentration.

With 60–80 parts of phosgene per million of air, Stage 1 is prolonged beyond that at the higher concentration and the dilution persists for 4 to 6 hours. The succeeding increase in the total solids also develops more slowly and is not so great only being 16 to 18 per cent at 17 to 18 hours. More of these dogs survive the acute period and Stage 3 appears in the curve. The return to normal is practically complete by the forty-fifth hour.

TABLE XXIV

Total Solids of Blood of Dogs Gassed with Phosgene

I. Animals Surviving the Acute Period

Dog No.	*Gas Conc. parts per million*	*Before Gassing*	*Total Solids in Per Cent of the Normal Value*																
			Hours after Exposure																
			1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*17*
P 725	38	100			90								97				95		
P 726	37	100			91				91				98				95		
P 730	50	100	98	96	97	95	96		95		95		96		97		97		
P 714	44	100	93	92	93	93		93		95	95			98		90		103	
P 711	41	100	105	106	107	107	107		107		107				104		107		
P 665	45	100	93				94				94				96				
P 713	43	100	100	100	98	100	101	101		102		102		104		106		112	
P 679	45	100		93	92	91	93		101		103		102		106		107		
P 699	49	100	99				104				110				108				
P 680	43	100	111	118	114	116	117		119		124		122		128		131		
P 683	54	100			82				84				91				96		
P 666	53	100	91	88	90	89	90		93		98		97		99		101		101
P 670	54	100	88	88	88	89	86		104	95				97		94		104	
P 669	53	100	88			95					100				107				112
P 668	55	100	89	86	86	85		90		95		96				99		106	
P 654	55	100	97	96	96	96			100		104		105		110		110		111
P 667	56	100	92	96		96	98		105		113		117		119		120		117
P 652	54	100	103	98	95	96	100		108		103		105		109		113		111
P 653	54	100	93	89	96	96			100		107		110		114		119		120
P 728	57	100	96	95	94	98		98		101		104		108		109		109	
P 199	67	100	95			96			96						104				
P 123	69	100	96	98		98			107										109
P 166	64	100				107	95												
P 127	65	100	95		95				99		100								
P 624	65	100	97		100				99			106							
P 196	63	100		95				100			111				115				
P 426	65	100				112													127
P 434	79	100	93				99					99				100			
P 428	71	100		96				101				106				114			
P 429	74	100		93				97				101				104			
P 206	75	100	110						108										122
P 383	77	100	98			101				100									
P 284	91	100			95		94				99								
P 710	94	100	89												104				101
Average			92	90	95	98	98	100		102.5		102.5		106.5			106.0	111.0	

TABLE XXIV (*Continued*)

TOTAL SOLIDS OF BLOOD OF DOGS GASSED WITH PHOSGENE

I. Animals Surviving the Acute Period

Total Solids in Per Cent of the Normal Value
Hours after Exposure

18	*19*	*20*	*21*	*22*	*23*	*24–25*	*26–27*	*28–29*	*30–31*	*32–33*	*34–35*	*36–37*	*38–39*	*40–41*	*42–43*	*44–45*	*45–50*
	92						94			95							
							100				93						
98				99		100											
	105				102			103							100		
108			109			107		105					104			99	
103					101		104										
	111			113				117					114			112	
110			110			107		128									
112				118				113			105						
129			129			129		109									
	95				97												
	104			106		108			106			103					
103			106			111			98			102					
						111			106		105						96
			111				112		97			100					
	113		113		114		110									104	
	117					109			104			100					
	113		116		115			109						105			
	118		120		123			118						108			
	113				115		108						107				
					101		101		98			99					
			108			107	105								102		95
						105	102		101								91
					101	105	107		106		96	100					94
						108	105		101			99					
	124		126			122	115		116	117				116		104	103
						110	107		106								100
111				112			106		114								109
103				102		118	110										
		117				111			114						94		101
				108		105			102			99				95	92
	108.5			112.0		115.0		108		104		101			104.5		98

TABLE XXV

Total Solids of Blood of Dogs Gassed with Phosgene

IIA. Animals Dying During the Acute Period

			Total Solids in Per Cent of the Normal Value *Hours after Exposure*															
Dog No.	*Gas Conc. parts per million*	*Before Gassing*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*
P 724	43	100				94			92				109				116	
P 729	50	100	90	91	91	92	101	112		120								
P 723	46	100			98				110				122				119	
P 712	48	100	119	116	114	116	114		114		120		127		133		141	
P 698	58	100	103				101				118							
P 684	53	100			101				110								125	
P 486	69	100	93			103					111				112			
P 124	67	100	89		90		103				115			121				
P 350	67	100				101				105				110				121
P 368	69	100		99				105				110						
P 727	61	100	93	95	95	101		113										
P 426	79	100																113
P 386	78	100		91														
P 431	71	100	99				101				111				117			
P 361	77	100		86				91										
P 395	79	100		86				100										
P 139	88	100	89		98			111										
P 140	88	100	92		97		96				109			118				
P 322	87	100		100				108				118				121		
P 351	89	100		99				113										
P 257	93	100	90			94			109			115						
P 406	114	100	90			94			103					124				
Average			95	96	98	99	102.5	106.5		113.5		118.0		118.5			122.5	

IIB. Normal Control

P 466																		
P 469					101													
S							99											
P 275						100												
P 276					103		96				96					96		

TABLE XXV (*Continued*)

TOTAL SOLIDS OF BLOOD OF DOGS GASSED WITH PHOSGENE

IIA. Animals Dying During the Acute Period

Total Solids in Per Cent of the Normal Value
Hours after Exposure

17	*18*	*19*	*20*	*21*	*22*	*23*	*24–25*	*26–27*	*28–29*	*30–31*	*32–33*	*42–43*	*45–50*
		116				115				112			
144			152			152			157				
			125				123		122				
	130				136			134					
		109			110								
		122											
						125		122					
						121							
	120				116								
						107		103					
						106							
	123.5				123			125					
	101						98					101	100
					99		99					93	95
							107					97	102
							102	97					96
							97	98		96			

At the lowest concentration studied, 40–60 parts per million, the changes are still less in degree. The dilution period extends over 6 to 8 hours and the maximum concentration of 12 to 14 per cent is not gained until 21 to 22 hours after exposure. Stage three is very similar to that with the intermediate concentration. Compared to the other two series but a very few dogs in this group died.

A study of the average results outlined above would indicate a very distinct relationship between the phosgene concentration and both the rate and degree of change in the blood. As has been mentioned before practically all the dogs in the first group died acutely while but very few died in the last group. The dogs in the second series are about equally divided between those that died acutely and those that survived the acute period.

Careful analysis of these results indicates (see Figure 15) that within each group the changes in the blood concentration show characteristic differences depending upon the ultimate fate of the animal. In those dogs that die acutely the period of dilution is short and the normal is regained within 3 to 5 hours. This is followed by an extremely rapid concentration that reaches a maximum of 22 to 23 per cent over the normal 15 to 16 hours after gassing. All these dogs die during this period of greatest blood concentration.

The survivals show a different picture (see Figure 15). The initial period of the reaction is slower, up to the sixth to tenth hour. Owing to the marked variation among individuals no distinction can surely be made between the acute deaths and survivals on the basis of the degree of dilution during this primary stage. The difference in time, however, is marked. The great difference, however, comes in the second stage, for the dog that ultimately recovers shows a very much slower development of the blood change and in addition

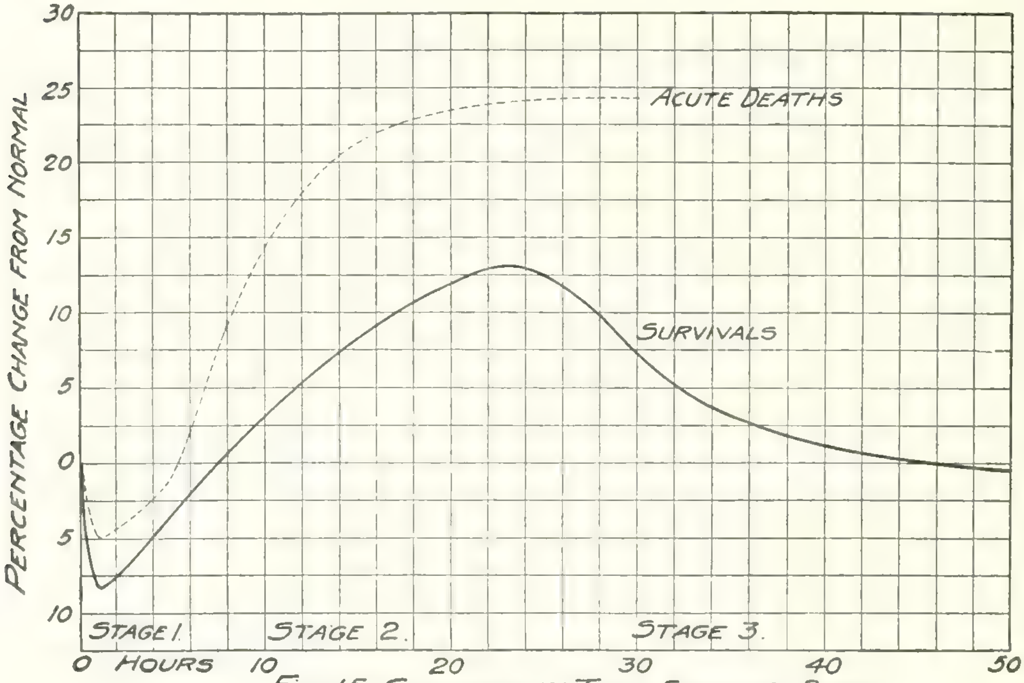

Fig. 15. Changes in Total Solids of Blood After Phosgene Poisoning.

the concentration is not nearly so marked, 12 to 15 per cent 22 to 24 hours after gassing. Following this comes the stage of recovery which has already been discussed.

These two types of classification with the reaction characteristic of each hold throughout the range of gas concentration studied. On the basis of this generalization it may be pointed out that the apparent correlation between response and phosgene concentration in the previous experimental series was due to the relative predominance of two separate types of reaction and not to the gradual change in the type of reaction by individual animals.

From these graphs it is quite apparent that three distinct stages may be recognized as occurring in the blood solids subsequent to phosgene poisoning.

The first stage is apparently one of dilution of the blood as evidenced by a decrease in the blood solids. This dilution is greatest, one to three hours after gassing and the total solids have returned to normal by the fifth to eighth hour. The cause of this sudden decrease in blood solids is not entirely clear.

The second stage is one of blood concentration. The total solids of the blood increase rapidly to a value far above the normal and remain stationary at this level for several hours. In the dogs gassed at 90 parts per million the average value for the total solids increased up to a maximum of 25 per cent ten hours after gassing and remained at approximately that level until the death of the dog. In those animals gassed around 70 parts per million the average value does not reach a maximum until some 17½ hours after gassing and even at this time the value is lower (23 per cent) than in the case of the higher gas concentration. The speed of blood concentration and the degree are both greater with the higher gas concentration.

Stage three marks the gradual return of the blood solids to the normal level.

Owing to the greater density of the red corpuscles of the blood as compared with the plasma any change in the relative amounts of corpuscles and plasma will cause a corresponding change in the total solids. The observed changes in the blood solids, therefore, might be due either to an increase in the plasma volume during stage one followed in stage two by a decrease and with no change in the erythrocytes; or else to the withdrawal of erythrocytes from the circulation in stage one and a later reintroduction. According to Lamson such changes are possible through the mediation of the blood sinuses of the liver. If the first of these possibilities is correct then the blood volume should be increased during the first phase and decreased later when concentration occurs. The reverse would be true in the second case.

Eyster reports that radiographs taken during the early stages of phosgene poisoning show a dilated heart, but without an increased plasma volume. On the other hand in the second stage the heart is markedly decreased in size.

From the foregoing it is evident that the changes in the concentration of the blood as determined by total solids gives one a method of following the condition of the animal in this respect.

The changes in concentration might equally well be followed by the determination of the hemoglobin. Hemoglobin determination is much more rapid, less blood is necessary, and the method is even more accurate than the more cumbersome total solid determination. Accordingly a comparison has been made between the hemoglobin content and the total solids of the blood, the results of which are expressed in Fig. 16. From this it may be seen that the two curves are similar but not parallel, and that the degree of change in the hemoglobin at all periods after phosgene poisoning is much greater than is true for the total solids. The hemoglobin, therefore, is a much more delicate indicator of the animal's condition than is the total solids. It has, therefore, been employed to estimate the changes in blood concentration.

A series of hemoglobin determinations has been made upon a comparatively large number of dogs gassed with phosgene at concentrations varying from 41–80 parts per million of air (0.17–0.35 mgm. per liter). On the basis of these studies the following different types of individual reactions, together with the probable fate of the animal, may be outlined.

Type I. The reaction of the animal is slight, there being a variable degree of dilution followed by a return to the normal hemoglobin value Stage 1 alone is apparent in this case, the concentration being absent. The recovery of the animal is uninterrupted after the passage of the dilution.

Type II. This type follows the usual stages of blood change, all three stages being present. The concentration in the second stage is relatively moderate varying up to 140 per cent of the normal. Under these conditions the animals recover.

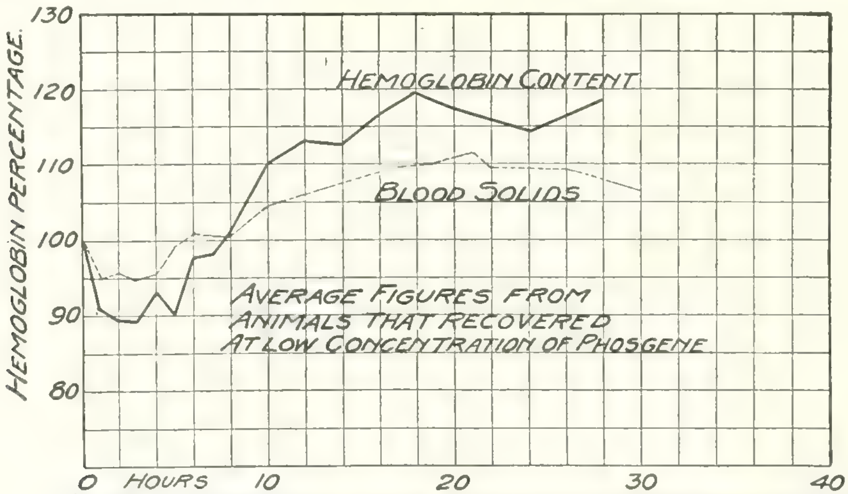

FIG. 16. COMPARISON OF TOTAL SOLIDS AND HEMOGLOBIN CONTENT IN THE BLOOD AFTER PHOSGENE POISONING.

Type III. This type is differentiated from the second type by the degree of concentration of the blood. Concentration of over 140 per cent is usually fatal. Death usually occurs in Stage 2.

The fate of the animal is dependent on two factors: (1) the degree of the concentration of the blood, and accordingly the extent of the edema, and (2) the individual resistance. In general, however, it has been found that a concentration of 140 per cent marks the mean between the two conditions. Hemoglobin readings above this indicate the probable death of the animal; below this, the recovery.

Type IV. This type is characterized by the absence of any dilution following gassing. The concentration appears immediately, or within the first two or three hours. The blood changes in this case are rapid and extreme, and are usually followed by early death.

Earlier in this Chapter it was reported that on the basis of the changes in the total solids the animals could be separated into two groups, one of Acute Deaths, and a second of Survivals. These two classes are practically synonymous with the reaction Types II and

III as outlined above. On the basis of the greater number of animals studied it has been possible, in addition, to characterize Types I and IV.

These are the changes in the blood as indicated by the hemoglobin readings. The individual type of reaction seems to be characteristic of no particular gas concentration, as examples of each type were found at all concentrations studied. With the increasing toxicity of the higher gas concentration, greater proportions of the animals showed reaction in order of Types III and IV, while at the lower concentration Types I and II predominated. The number of animals studied at each gas concentration is not great enough to permit of a percentage analysis. In the discussion of the result at each gas concentration, however, this factor of the different types of reaction must be kept in mind. In Table XXVI are given data showing the average * figures obtained when the results are divided into (1) Recoveries, (2) Acute Deaths, and (3) Delayed Deaths.

TABLE XXVI

Hemoglobin Changes in the Blood in Phosgene Poisoning

Percentages

	Average Recoveries				Average Acute Deaths				Average Delayed Deaths			
No. of dogs	*21*	*26*	*10*	*7*	*4*	*9*	*10*	*7*	*3*	*3*	*2*	*5*
Hours Conc.	*41–50*	*51–60*	*61–70*	*71–80*	*41–50*	*51–60*	*61–70*	*71–80*	*41–50*	*51–60*	*61–70*	*71–80*
0–1	96	94	88	94	89		93	99	92	91	93	94
1–2	90	91	90	81	89	91	88	104		97		88
2–3	92	92			90	96	97		91	103	97	93
3–4	92	94	87	86	90	98		105	93		104	
4–5	93	94	89	91	102	108	98			99		93
5–6	98	96	90	92	113	111		109	91	101		
6–7	99	98	96	89	116	124	98			109	109	93
7–8			98					117	106	114		
8–9	105	107			139	131	112					95
9–10				94				136	118	118		
10–12	110	112	114	115	144	135	133	138			115	112
12–14	110	115	117			147	135		121	139		
14–16	116	117		117	166	152	132	137	119		153	123
16–18	114	119	119			153			119	154		
18–20	120	124	115	113		150	135	138	108		140	122
20–22	119	120	108						105	130	155	
22–24	109	113		112					104			
24–26	112	116		113								
26–28									90	140	115	
28–30				106								
30–32											129	

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* The individual data may be found in the Appendix, Chapter VI, page 266.

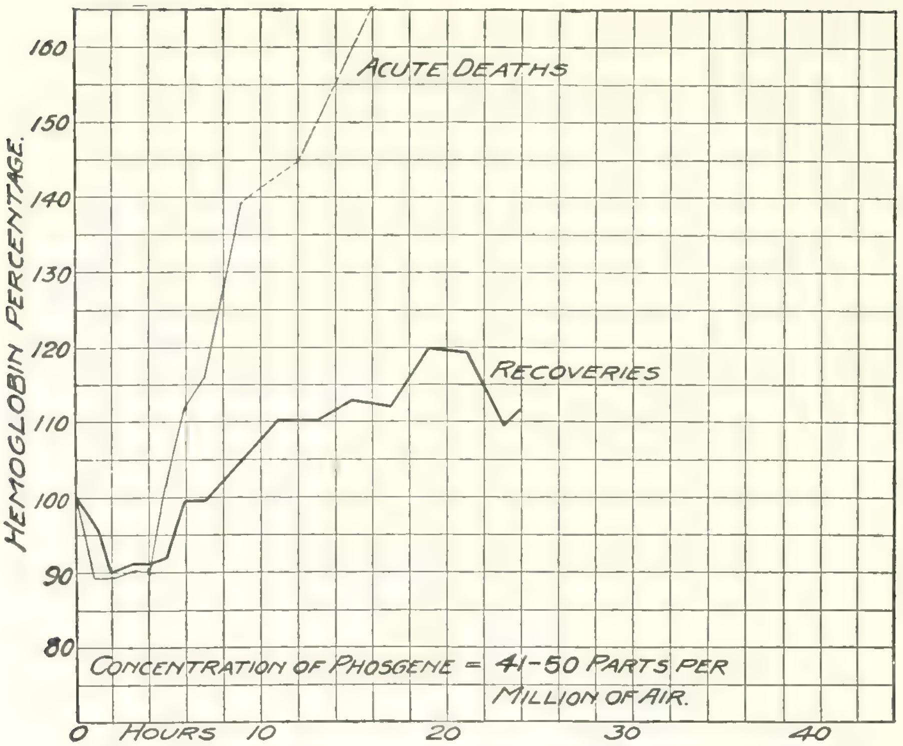

Fig. 17. Changes in Hemoglobin after Phosgene Poisoning in in Percentage of Normal-Average Figures.

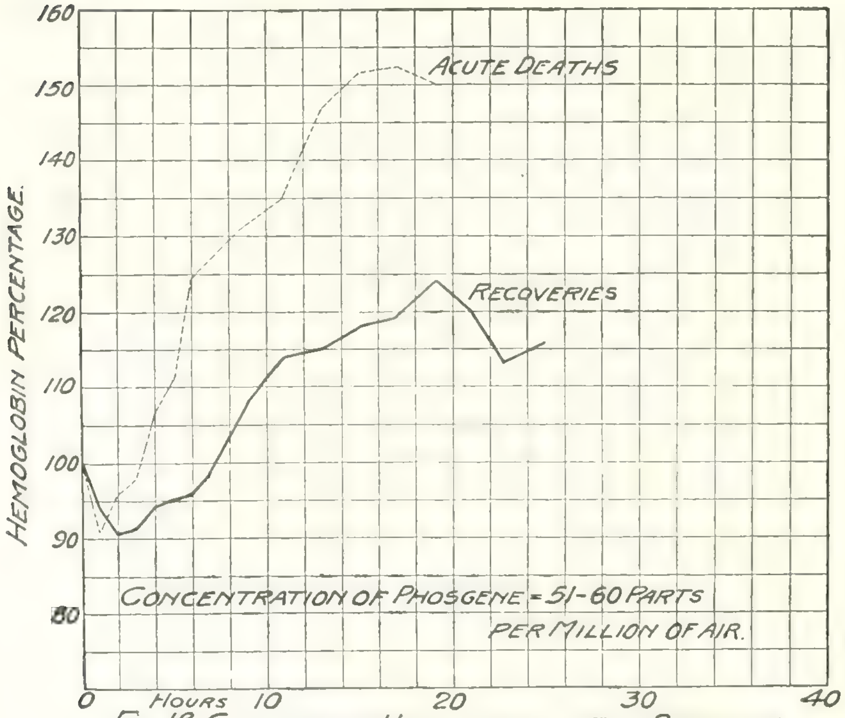

Fig. 18. Changes in Hemoglobin after Phosgene Poisoning in Percentages of Normal-Average Figures.

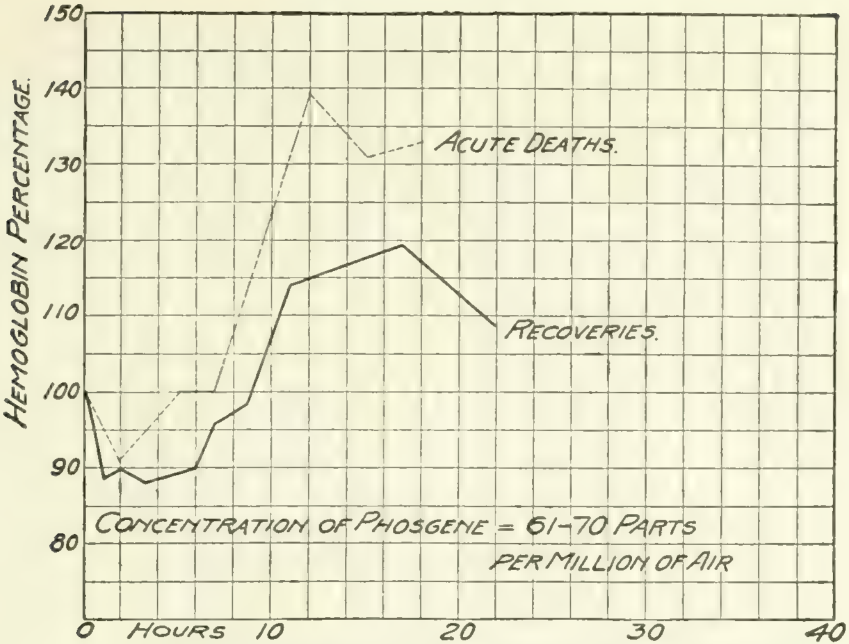

Fig. 19. Changes in Hemoglobin after Phosgene Poisoning in Percentage of Normal-Average Figures.

Recoveries

Dogs gassed at 41–50 and 51–60 parts phosgene per million of air are affected about equally, i. e., 72 per cent survivals and 28 per cent deaths, and 69 per cent survivals and 31 per cent deaths respectively. The average hemoglobin picture shown by these two concentrations is almost identical. The first stage shows a dilution of 90 per cent of the normal hemoglobin in the second hour, this being followed by a gradual increase until the normal concentration is reached between the seventh and eighth hours. (Figs. 17 and 18.)

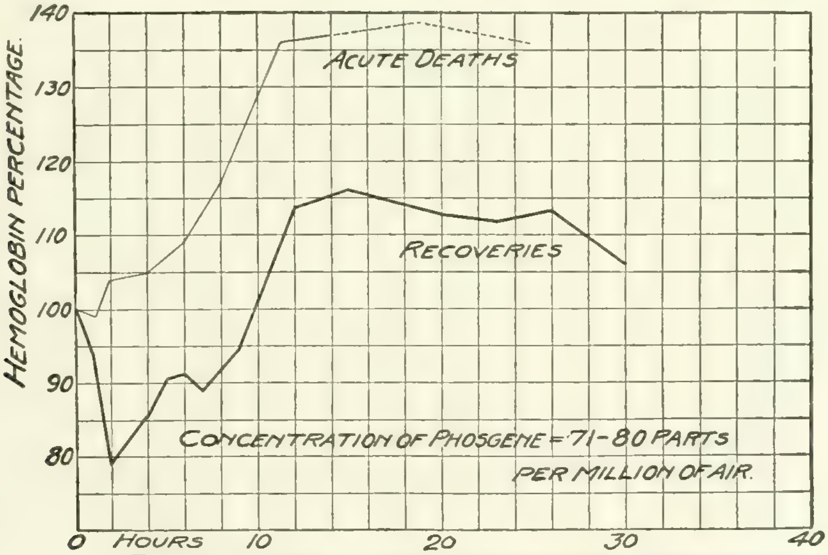

Fig. 20. Changes in Hemoglobin after Phosgene Poisoning in Percentage of Normal-Average, Figures.

There is then a gradual concentration of the blood until the maximum of 125 per cent hemoglobin is reached in the nineteenth hour. The blood begins then to dilute and reaches its normal concentration about the thirty-sixth hour.

As the concentration is increased (61–70) the toxicity is markedly changed—recoveries 45 per cent, deaths 55 per cent. The time factor in the average hemoglobin curve is slightly changed, but the curve (Fig. 19) as a whole is not altered. The blood dilutes to 87 per cent of the normal concentration one hour after gassing and remains constant until the fifth hour. The blood reaches its normal concentration in the ninth hour and continues to concentrate until a maximum hemoglobin concentration of 120 per cent is reached in the 17th hour. The return to normal then follows.

At the concentration of 71–80 parts per million phosgene the recoveries total 37 per cent and deaths 63 per cent. Following gassing there is a minimum dilution (Fig. 20) of 81 per cent after two hours, this being followed by a gradual increase until the tenth hour. Between the ninth and eleventh hours there is a marked increase of 20 per cent—a jump in two hours from below normal to its maximum concentration (116 per cent). The hemoglobin curve remains constant until about the 25th hour and then begins its return to normal.

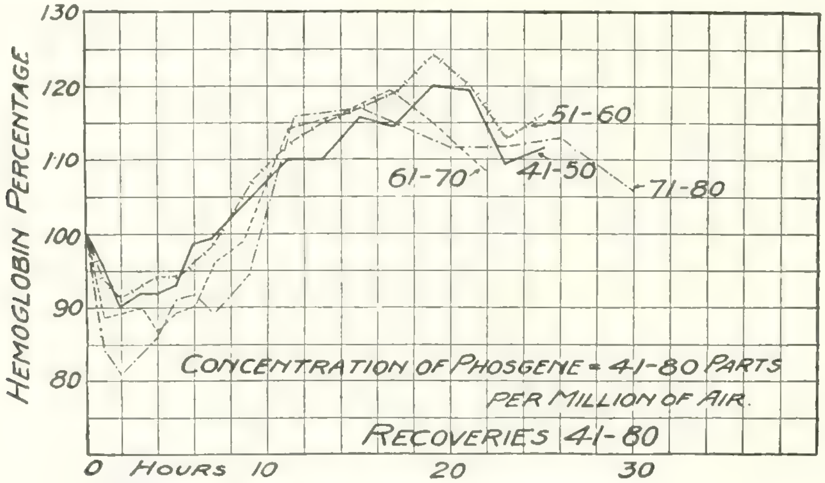

Fig. 21 Hemoglobin Changes in "Recovery" Curve.

From the above discussion, the following facts may be observed (Fig. 21):

1. The blood is most dilute between the first and third hours after gassing.
2. The return to normal after the dilution takes place sooner at low than at high concentrations.
3. The time of maximum concentration of the blood during stage two depends on the phosgene concentration; the higher the gassing, the sooner is this point reached.
4. The average maximum concentration for recovered animals is about 120 per cent of normal hemoglobin.

Acute Deaths

The acute deaths have been classified as those dogs dying within 36 hours after gassing. The number of dogs dying within a few hours is relatively small, so that an average curve is not indicative of great accuracy. The individual type of hemoglobin curve may be discussed to better advantage.

The most common type of curve (Fig. 22) is one in which there is a significant dilution followed by a very marked rise in hemoglobin. The time when the concentration begins varies from 3 to 10 hours after gassing and is not dependent on the concentration of the

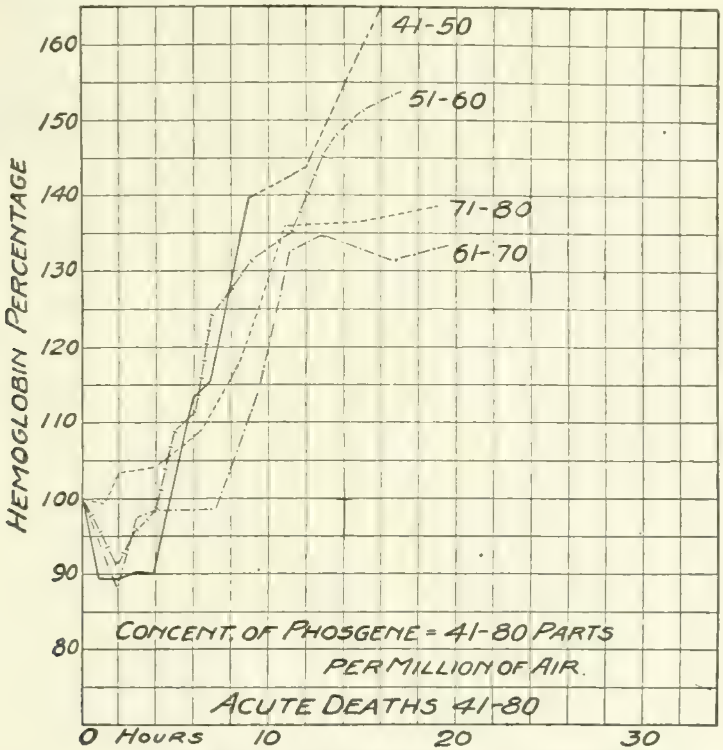

Fig. 22 HEMOGLOBIN CHANGES IN INDIVIDUAL CURVES OF "ACUTE DEATHS"

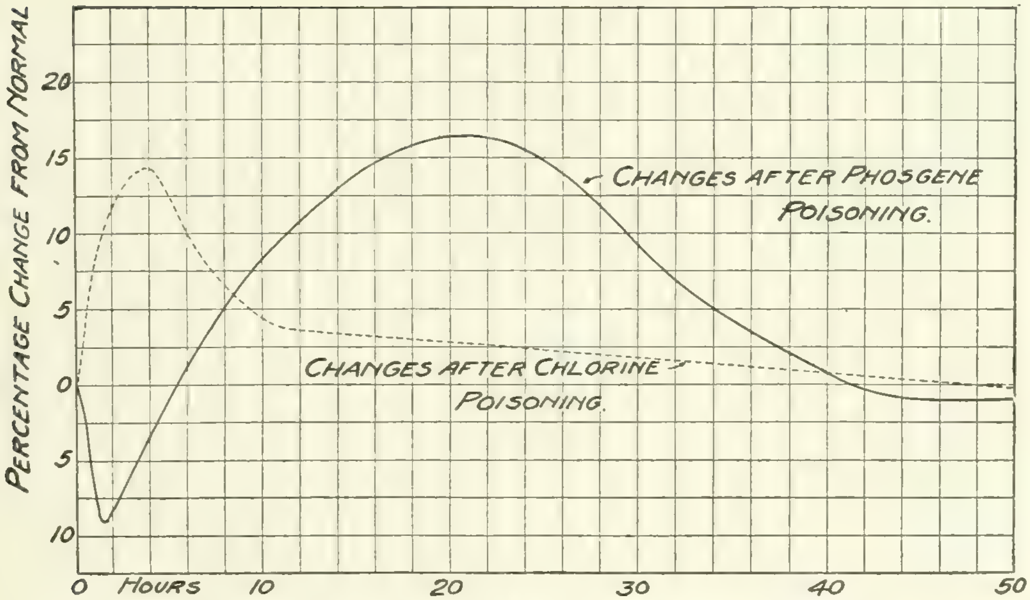

Fig. 23. COMPARISON OF CHANGES IN BLOOD SOLIDS IN CHLORINE AND PHOSGENE POISONING.

gas or the dilution of the blood during Stage 1. Another type which invariably proves fatal in phosgene poisoning is an immediate concentration of the blood. The faster the blood concentrates, so much the sooner does the animal die. In certain instances, a dilated heart may cause an acute or delayed death without any sign of significant blood concentration. This, however, is seldom seen.

With chlorine too few experiments were made to warrant more than the most general statements relative to blood concentration changes. The data in Tables XXVII, XXVIIa and XXVIIb, however, allow one to be certain that the course of blood concentration alterations, as determined by estimation of the total solids, parallels the curve obtained by determination of the hemoglobin values. These data also indicate quite clearly that the period of blood dilution, that is, Stage 1 in phosgene poisoning, is either very slight and short lived or lacking altogether, and that the significant feature relative to the blood changes under discussion in chlorine gassing is the almost immediate tendency for concentration and the rapid development of this to a high maximum. (Cf. Fig. 23.)

The striking feature in blood changes as indicated by total solid determination after chlorpicrin gassing is the usual absence of the first or dilution stage which characterizes phosgene. In surviving dogs the blood steadily concentrates and attains its maximum about ten hours after gassing. Very gradually the blood then becomes less concentrated until about the fortieth hour it has usually reached its normal value, and becomes then, for a time, less concentrated than normal (see Table XXVIII, and Figs. 24–29, inclusive), also Appendix, Chapter VI, page 272.

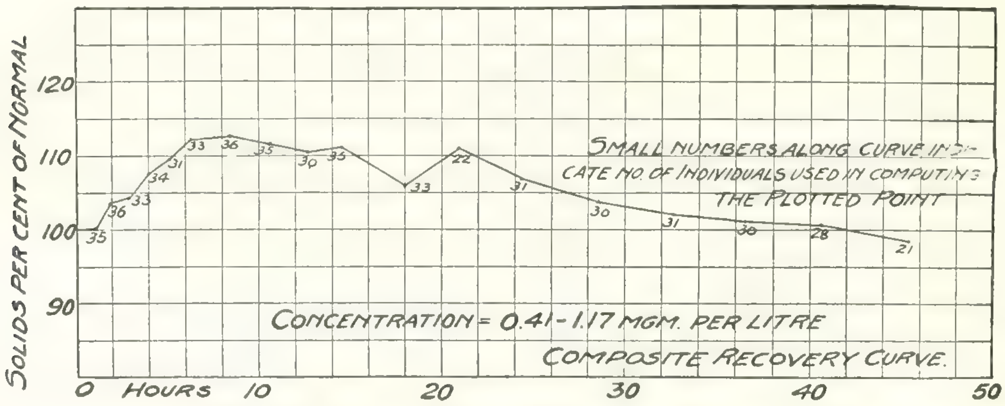

Fig. 24. BLOOD SOLID STUDIES IN CHLORPICRIN DOGS.

On the other hand 20 of the 58 chlorpicrin dogs studied show a dilution period corresponding to the first stage in phosgene. This lasts for a variable interval, but is usually less than two hours, often less than ½ hour in length. In all but three cases the maximum dilution value was found in blood collected within the first hour after gassing. No animal showing this dilution died. The only two animals able to survive gassing above 1.09 mgm. per liter exhibited this dilution stage.

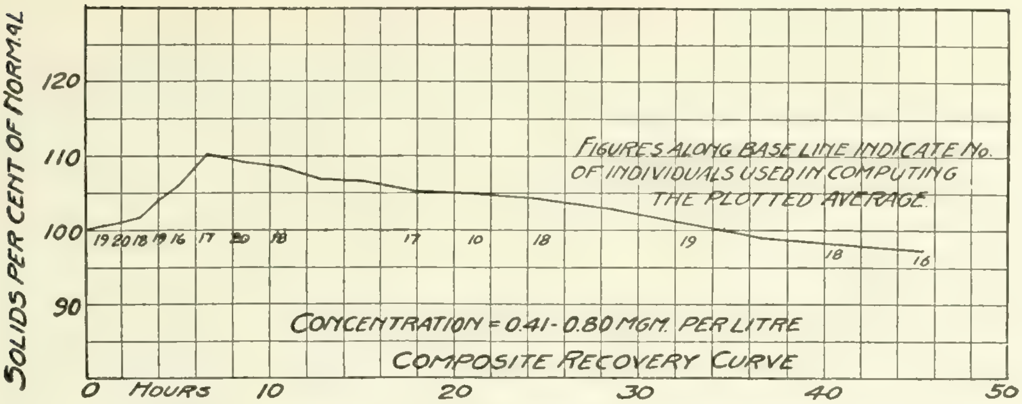

Fig. 25. BLOOD SOLID STUDIES IN CHLORPICRIN DOGS.

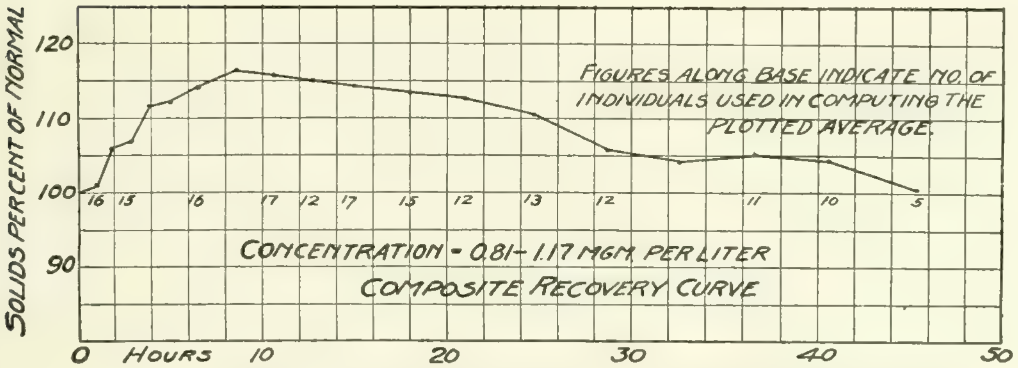

Fig. 26. BLOOD SOLID STUDIES IN CHLORPICRIN DOGS

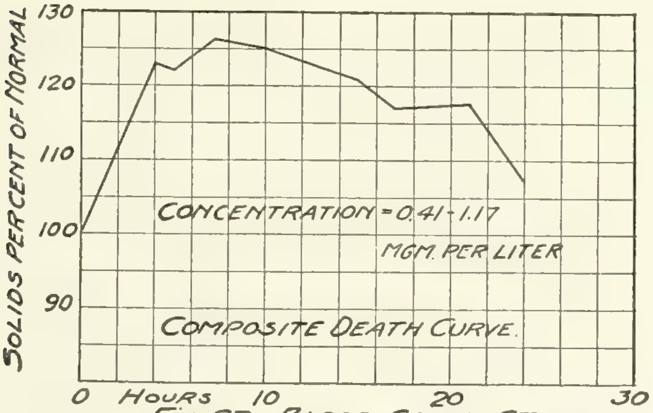

Fig. 27 BLOOD SOLID STUDIES IN CHLORPICRIN DOGS.

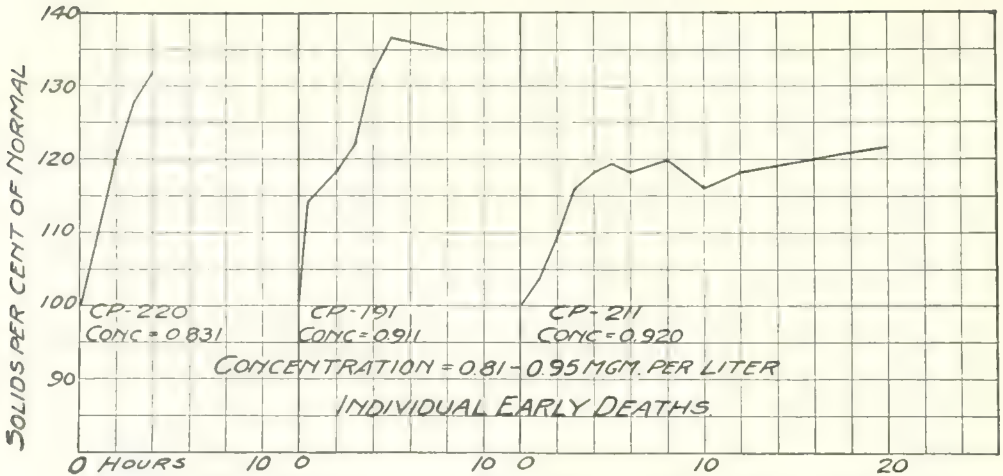

Fig 28 Blood Solid Studies in Chlorpicrin Dogs.

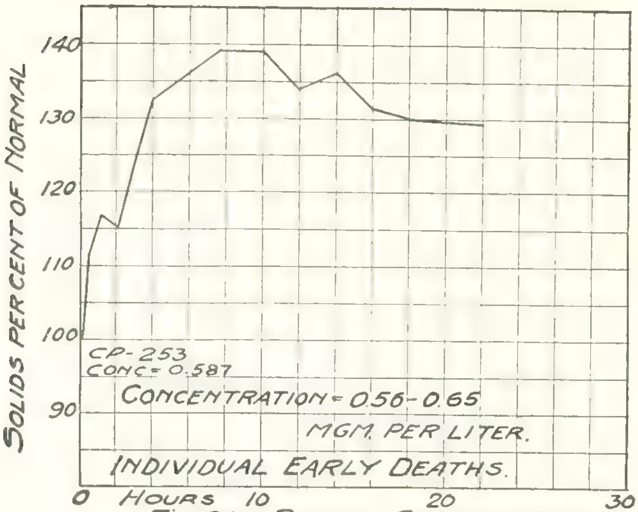

Fig. 29. Blood Solid Studies in Chlorpicrin Dogs.

TABLE XXVII

TOTAL SOLIDS OF WHOLE BLOOD AFTER CHLORINE POISONING

Dog No.	*Gas Conc.*	*Expo-sure*	*Before Gassing*	*Hours after Exposure*												
				0	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*9*	*25*	*30*	*40*	*70*
	Mgm. per Liter	*Min.*	*Per Cent*							*Per Cent*						
404	1.91	30	20.5	21.2	21.6	21.6	21.8	21.6		21.7		21.4	20.1	20.1	20.1	19.0
396	2.48	30	22.6	23.6	24.5	25.6	25.8	25.6			24.7			20.8	22.6	
395	2.51	30	21.3	22.3												
2[2]	3.39	30	15.7	16.9			17.7			17.5						
7	3.98	60	20.1			23.4										
17	4.20	60	20.9	23.7			25.3		26.7							
10	1.19	120	16.3	18.8		18.8		18.0					17.7			
14	1.40	120	23.7	24.1		24.5		23.3					19.9			

TABLE XXVIIA

Hemoglobin Content of Blood in Chlorine Poisoning

Recoveries

Concentration = 800 parts per million of air (2.53 mgm. per liter)

Dog No. *Hours*	*528*	*529*	*Average*
0–1	114 *	112	113
1–2	115	115	115
2–3	111	145	128
3–4	122	158	140
4–5	131	155	143
5–6	122	159	140
6–7	125	160	143
7–8	125	145	135
8–9	116	164	140
9–10	125	164	144
10–11			
11–12	119		
12–14			
14–16			
16–18			
18–20	132	149	
20–22			
22–24	119	147	
24–26			
26–28			
28–30			
30–32			
32–34		158	

* Figures are in percentages of normal.

TABLE XXVIIB

HEMOGLOBIN CONTENT OF BLOOD IN CHLORINE POISONING

DEATHS

Concentration = 800 parts per million of air (2.53 mgm. per liter)

Dog No.	*530*	*531*	*532*	*533*	*534*	*535*	*Average*
Hours							
0–1	99 *		137	158	115	156	133
1–2	119		149	152	115	178	142
2–3	121	123	154	152		D	139
3–4	109	137		142			130
4–5	123	141	140	132	118		130
5–6	121	145	149		118		144
6–7	114	D	149	132			132
7–8	123		142		118		128
8–9	123		131				128
9–10				130			
10–11	123						
11–12							
12–14	134		126	127			129
14–16	D		123	125	159		135
16–18			124	D	D		
18–20			D				
20–22							
22–24							
24–26							
26–28							
28–30							
30–34							

* Figures are in percentages of normal.

TABLE XXVIII

Blood Solid Studies in Chlorpicrin Dogs
General Averages

	Grand Average of All Recovering Dogs		*Concentration 0.41–0.80 mgm. per liter*		*Concentration 0.81–1.17 mgm. per liter*		*Grand Average of All Early Deaths*
Hours	*Per cent* *	*No.*†	*Per cent*	*No.*	*Per cent*	*No.*	*Per cent*
1	100.1	35	100.1	19	100.8	16	108.1
2	103.5	36	101.4	20	106.0	16	113.3
3	104.7	33	102.3	18	107.3	15	119.6
4	107.2	34	104.2	19	111.5	15	123.3
5	109.2	31	106.3	16	112.3	15	
6 7	112.1	33	109.9	17	114.4	16	123.3
8 9	112.6	36	109.2	20	116.5	16	126.9
10 11	112.0	35	108.8	18	115.8	17	126.0
12 13	110.3	30	107.2	18	115.0	12	124.4
14 15 16	110.7	35	107.0	18	114.6	17	122.1 122.2
17 18 19	106.0	33	105.2	17	113.9	15	117.6
20 21 22	111.1	22	105.2	10	113.6	12	118.0
23 24 25 26	107.0	31	104.4	18	110.6	13	108.0
27 28 29 30	104.2	30	102.7	18	106.4	12	
31 32 33 34	102.3	31	100.9	19	104.6	12	
35 36 37 38	101.3	30	98.9	19	105.4	11	
39 40 41 42	100.6	28	98.2	18	104.8	10	
43 48	97.9	21	97.0	16	100.3	5	

* Blood solids are expressed in per cent of normal value.

† Number of individuals contributing to the average value.

The maximum concentration is about the same as in phosgene, averaging 113 per cent of normal. The extent of concentration is to a certain degree dependent on the gassing strength, as it will be seen that the blood of animals gassed below 0.80 mgm. per liter failed to become as concentrated as in animals gassed above this value.

Since from the standpoint of treatment, the time relations of blood concentration are important, a comparison is made in the following table between the effects of phosgene and chlorpicrin:

Average time at which maximum concentration is attained (Hours)

	Recoveries		*Early Deaths*	
Phosgene	19	(Average of 27 dogs)	13	(Average of 17 dogs)
Chlorpicrin	10	(Average of 38 dogs)	7	(Average of 7 dogs)

Extreme limits of time at which maximum concentration is attained (Hours).

Phosgene	4—30	5.5—28
Chlorpicrin	4—18	3—18

The concentration is attained earlier in chlorpicrin, but the variation in time is wide.

In dogs which suffer early death from chlorpicrin gassing, the rise to a maximum concentration value is swift. In several cases a concentration above 130 per cent normal is attained within five hours.

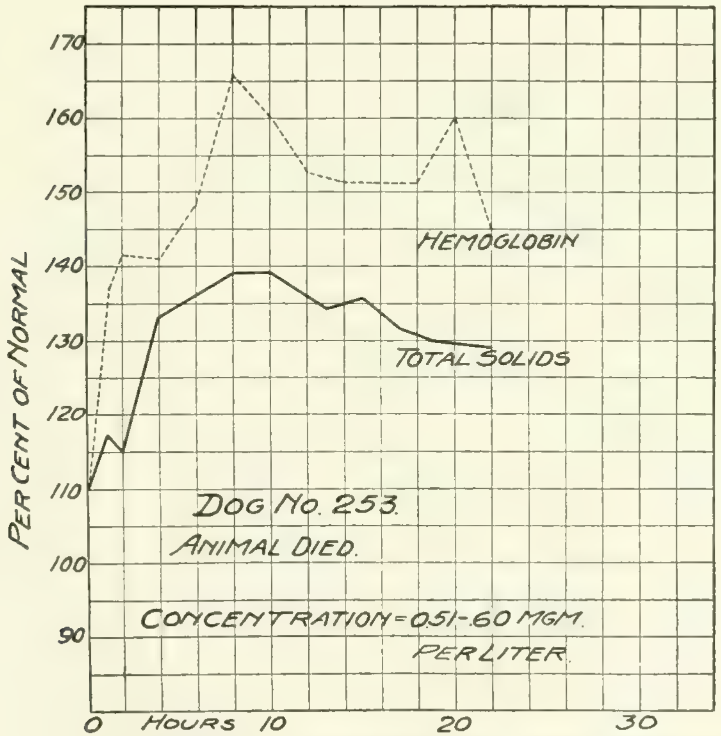

FIG. 30. COMPARISON OF TOTAL SOLIDS AND HEMOGLOBIN AFTER CHLORPICRIN POISONING

After reaching the maximum concentration the animal usually, not always, dies within a short time, within five hours. A comparison of the relationship between the total solid curve and that of the hemoglobin may be seen by inspection of Figs. 30, 31, and 32,

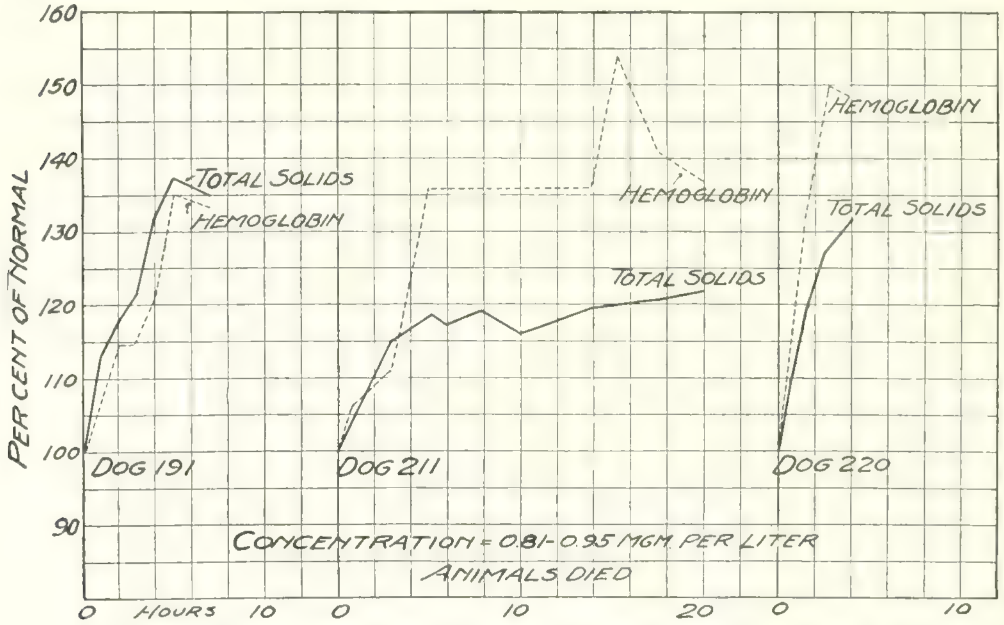

Fig. 31 COMPARISON OF TOTAL SOLIDS AND HEMOGLOBIN AFTER CHLORPICRIN POISONING

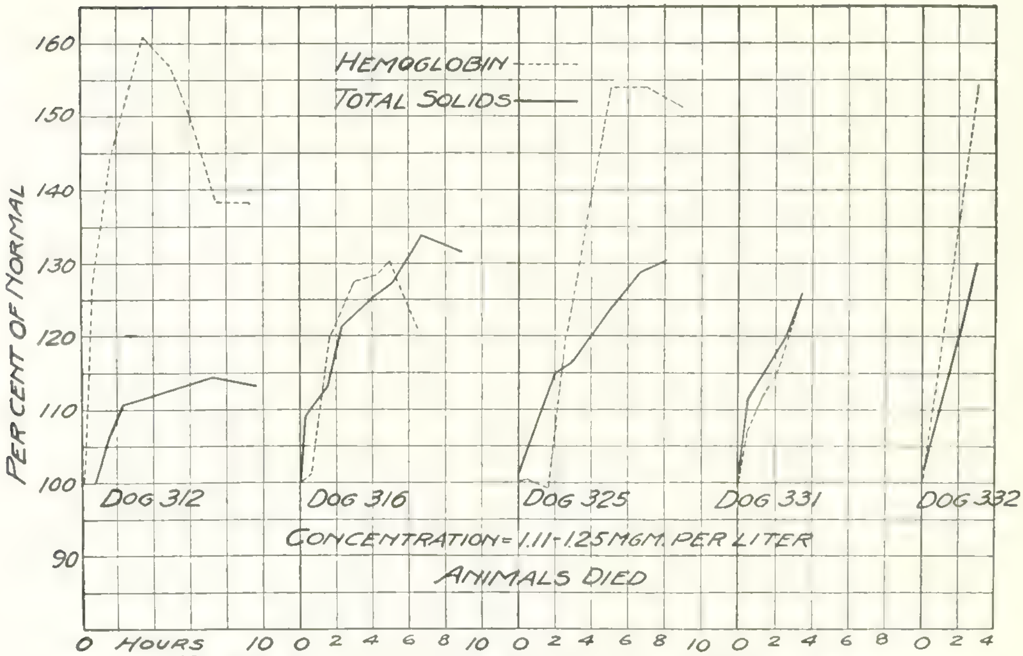

Fig. 32 COMPARISON OF TOTAL SOLIDS AND HEMOGLOBIN AFTER CHLORPICRIN POISONING.

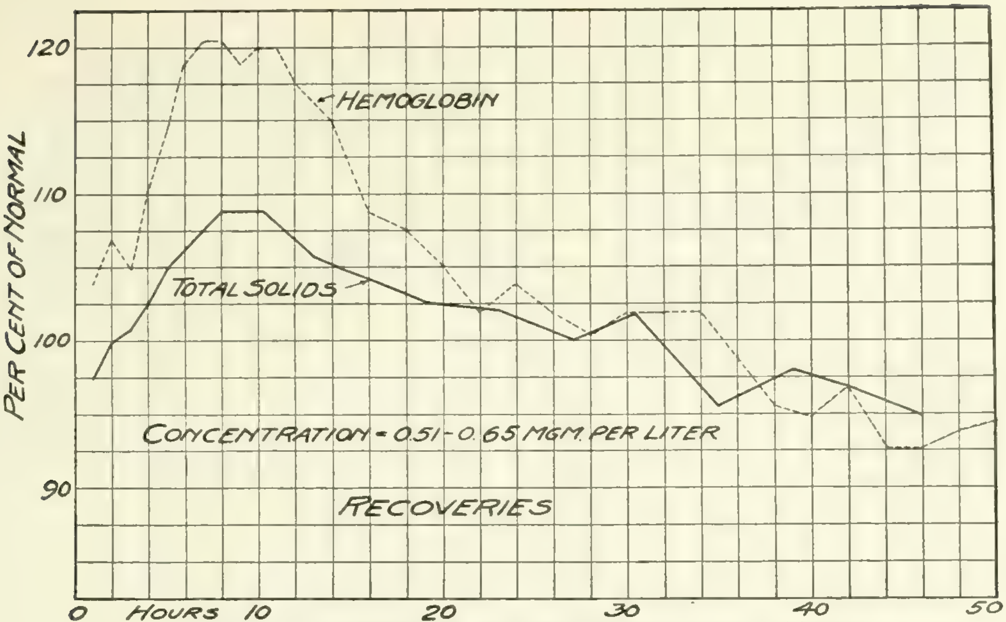

Fig. 33. COMPARISON OF TOTAL SOLIDS AND HEMOGLOBIN AFTER CHLORPICRIN POISONING.

made from data of total solids and hemoglobin estimated on the same animal. These graphs represent both curves of a single animal at different concentrations in order to show the various types of reaction encountered. Figs. 33, 34, and 35 are reproduced as examples of the recovery curves. The data from which these graphs were made may be found in the Appendix, Chapter VI, page 274.

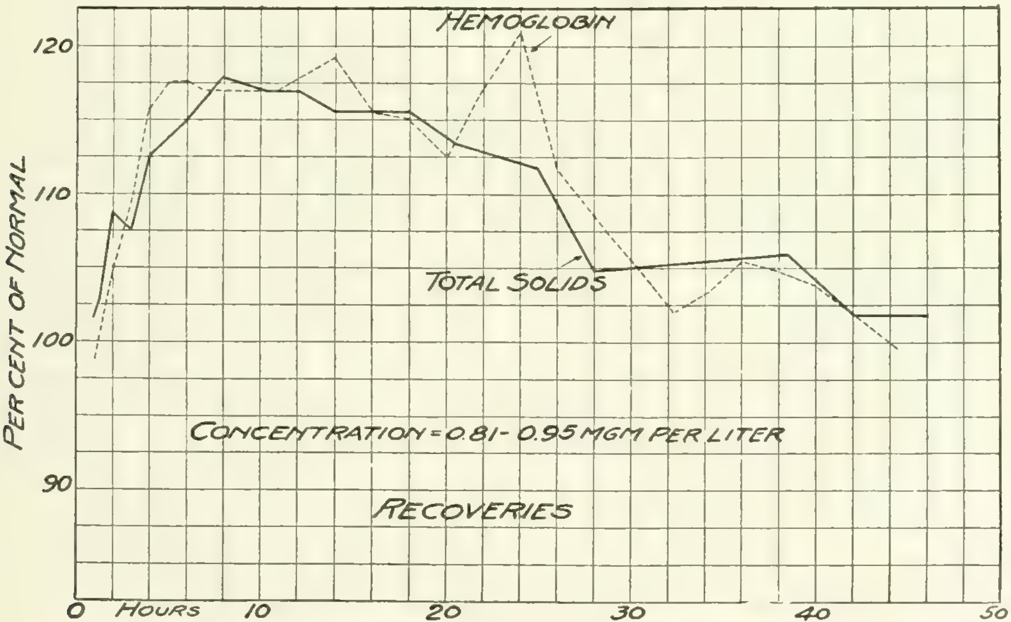

Fig. 34 COMPARISON OF TOTAL SOLIDS AND HEMOGLOBIN AFTER CHLORPICRIN POISONING

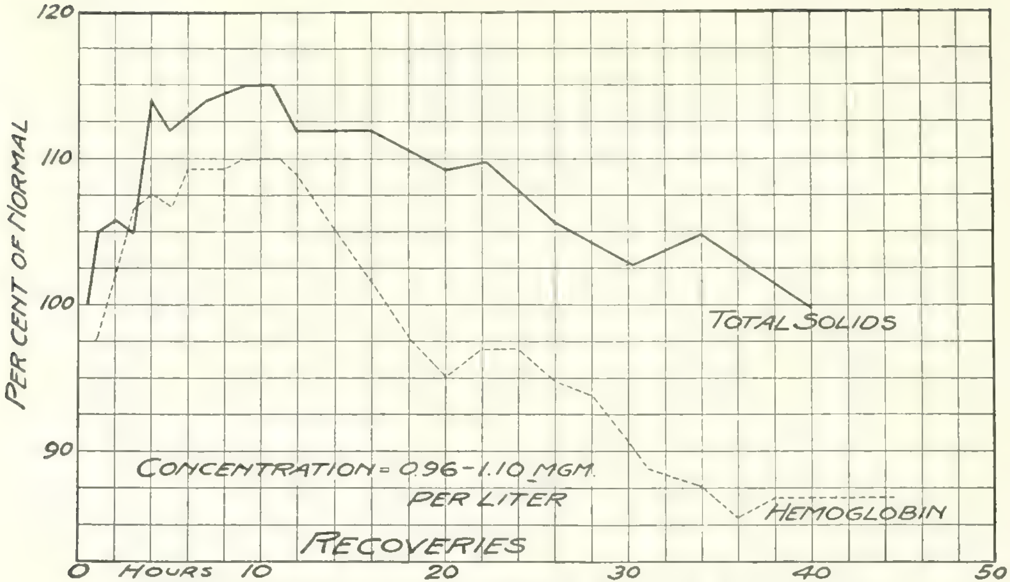

Fig. 35. COMPARISON OF TOTAL SOLIDS AND HEMOGLOBIN AFTER CHLORPICRIN POISONING.

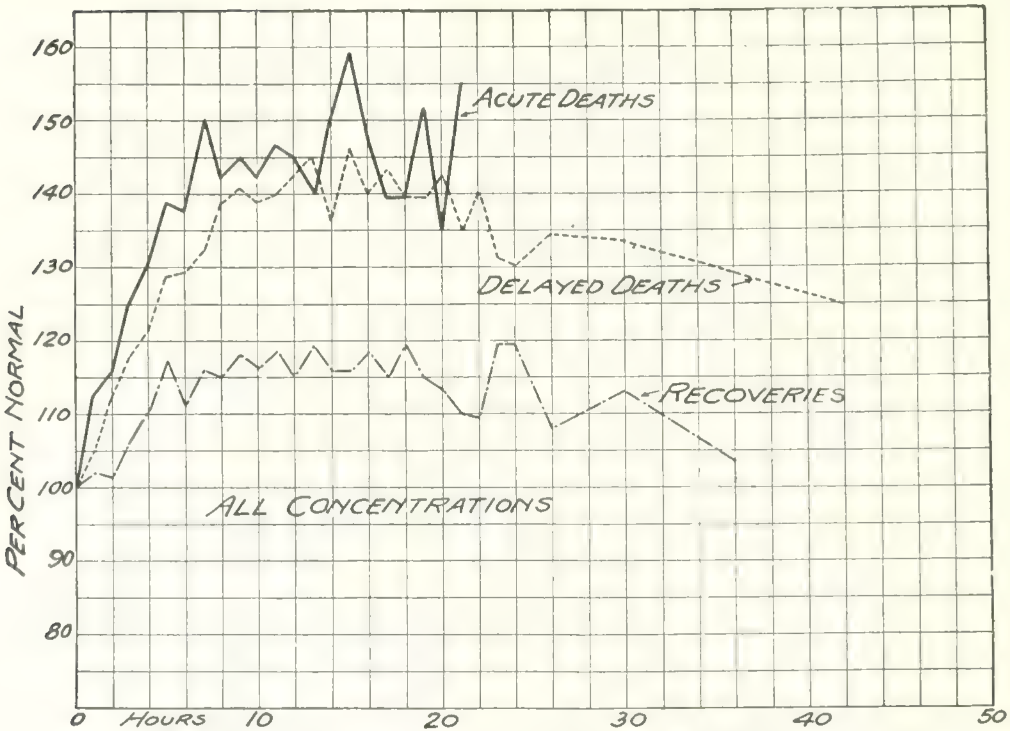

Fig 36 COMPARISON OF CHANGES IN HEMOGLOBIN CONTENT AFTER CHLORPICRIN POISONING

This comparison shows that the total solids and hemoglobin curves take courses that run nearly parallel, and it corroborates the conclusion previously expressed, that the hemoglobin may be employed as an accurate indicator of changes in blood concentration.

Figure 36 illustrates the relationship of changes in blood concentration of a large number of dogs exposed to chlorpicrin at various concentrations. It may be seen that the curves representing acute and delayed deaths follow a quite different course from that of the animals recovering. The data upon which these graphs are based may be found in the Appendix, Chapter VI, page 280.

If one draws characteristic curves of blood changes induced by the three gases, the diagram in Fig. 37 would be the result.

The most striking feature of the blood in relation to exposure to the lethal war gases is the marked change in concentration, which varies characteristically both in degree and time with the different gases. The significance which it is believed attaches to this phenomenon will be discussed in succeeding chapters.

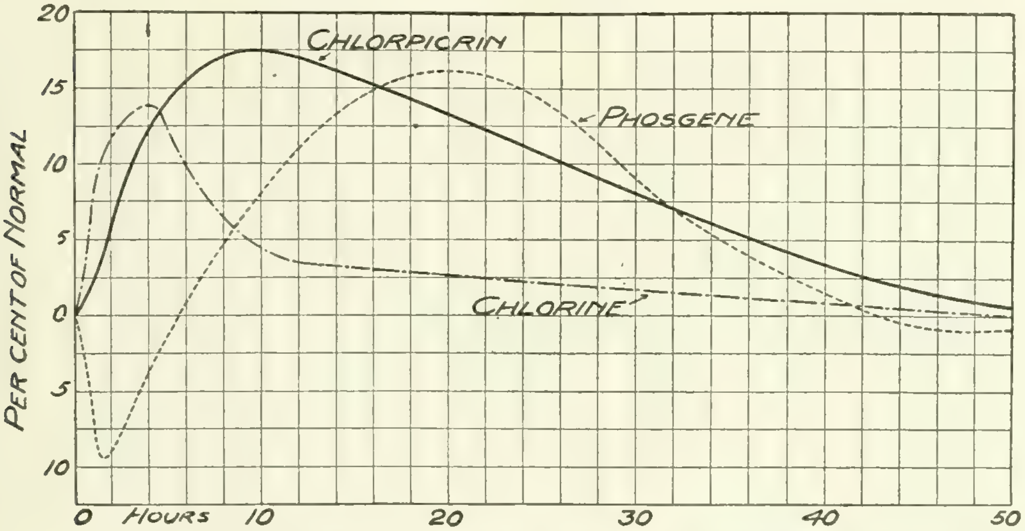

Fig. 37 Comparison of Changes in Blood Solids of Dogs Gassed with Chlorine, Phosgene and Chlorpicrin.

CHAPTER VII

THE RED AND WHITE CELLS OF THE BLOOD

A BRIEF study * has been carried through of the influence of the lethal gases upon the red and white cells of the blood and in certain instances comparison has been made of the changes in the red cells and the hemoglobin.

With chlorine observations were made first relative to the influence of gassing upon the red cells over an extended period, that is, cells were counted on successive days. The results of a few such experiments may be found in Table XXIX wherein are included corresponding data for hemoglobin content. In later work the red cell estimations were made more frequently at intervals of hours instead of days, and in Table XXX and Figure 38 a comparison between red cell content and hemoglobin values may be seen. From the data at hand it is indicated that almost immediately after chlorine gassing there occurs a characteristic rise to a high maximum of both red cells and hemoglobin. The graphs which may be plotted from the data more or less parallel each other. The increase in the red cell count, however, is usually somewhat greater than that of the hemoglobin value. The approximate parallelism for these two elements of the blood leads to the conclusion that

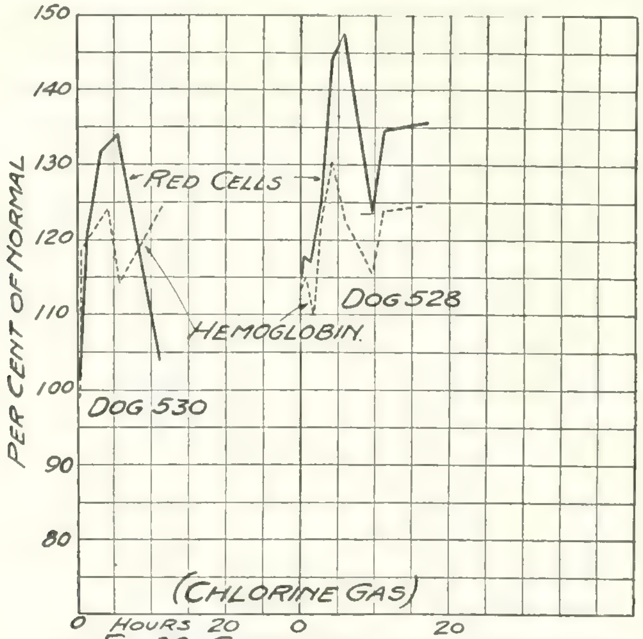

Fig 38. COMPARISON OF ERYTHROCYTES AND HEMOGLOBIN CONTENT OF BLOOD

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* For methods employed see Appendix to Chapter VII, page 290.

TABLE XXIX

Comparison of the Erythrocyte and Hemoglobin Content of the Blood Before and After Chlorine Poisoning

Dog No.	Date 1917	Before Exposure		Gassed	Date 1917	After Exposure	
		Red Cells	*Hemoglobin*			*Red Cells*	*Hemoglobin*
1	July 24	5,928,000	79.5	Aug. 6	Aug. 6		
				10 A. M.	11:30 A. M.	6,228,000	81.6
	“ 25	5,672,000	74.5	1.47	Aug. 6		
				mgm.	3:00 P. M.	6,116,000	83.6
	“ 26	4,952,000	64.3		Aug. 7		
					9:30 A. M.	5,748,000	77.5
	“ 27 A. M.	6,532,000			Aug. 7		
					2:45 P. M.	5,264,000	73.0
	“ 27 P. M.	5,936,000	78.0		Aug. 8		
					9:30 A. M.	4,916,000	60.0
	“ 28	5,124,000	66.3		Aug. 9	4,888,000	64.3
					“ 10	4,676,000	63.0
3	July 30 A. M.	7,500,000	82.0	Aug. 13	Aug. 13		
				9:21 A. M.	12 M.	6,884,000	87.6
	“ 30 P. M.	7,792,000		2.13	Aug. 13		
				mgm.	5 P. M.	6,840,000	89.0
	“ 31	7,172,000	83.5		Aug. 14 A. M.	6,600,000	82.6
	Aug. 1	7,316,000	79.3		“ 15 “	5,288,000	76.5
	“ 2	6,408,000	77.0		“ 16 “	5,968,000	78.0
	“ 3	6,608,000	77.5		“ 17 “	6,264,000	77.0
8	Aug. 20	5,192,000	63.6	Aug. 31	“ 31 “		
				10:50 A. M.	11:15 A. M.	6,208,000	77.5
	“ 21	5,336,000	70.0	3.79	Aug. 31		
				mgm.	1:15 P. M.	6,880,000	89.0
	“ 22	5,480,000	73.5		Aug. 31		
					3:30 P. M.	6,208,000	77.0
	“ 23	5,120,000	69.0		Sept. 1	Died	
					A. M.		
	“ 24	5,140,000	64.5				
	“ 31						
	10 A. M.	5,112,000	65.5				
28	Aug. 11	5,528,000	60.5	Aug. 11	Aug. 11		
				10 A. M.	11:00 A. M.	5,224,000	61.5
				2.91	Aug. 11		
				mgm.	1:00 P. M.	6,520,000	66.5
					Aug. 11		
					3:00 P. M.	6,008,000	60.5
					Aug. 15	Died	

TABLE XXX

Comparison of the Erythrocytes and Hemoglobin Content of the Blood

				Chlorine Gas					
Dog No.	*Date*	*Red Cell Count Normal*	*Hemoglobin*	*Gassed Parts per million*	*Hours after Gassing*	*Red Cell Count After Gassing*	*Hemoglobin*	*Red Count Per cent*	*Hemoglobin*
528	12/3	6,650,000	96	857	½	7,690,000	109	115	114
					1	7,870,000	110	118	115
					2	7,740,000	107	117	111
					3	8,400,000	117	126	122
					4	9,640,000	126	145	131
					6	9,810,000	118	148	123
					10	8,260,000	111	124	116
					12	8,996,000	119	135	124
					18	9,040,000	120	136	125
						D.			
530	12/4	9,020,000	123	804	½	9,200,000	120	102	99
					1	10,900,000	146	121	119
					2	10,940,000	149	122	121
					4	11,160,000	152	132	124
					6	13,980,000	140	134	115
					12	9,460,000	152	105	124
						D.			

the increase is apparent rather than actual. Stated differently the apparent changes in the red cell count and the hemoglobin figures are to be referred to changes in the concentration of the blood and cannot be accepted as evidence for the intrusion of new cells into the blood stream.

With phosgene a similar conclusion must be drawn with respect to alterations in the number of red cells—see Table XXXI. It will be observed here that shortly after gassing the cells diminish in number and later rise far above the normal value in harmony with the observed changes in blood concentration, namely, a period of dilution shortly subsequent to exposure to the gas followed by an interval when the blood becomes highly concentrated.

Chlorpicrin gassing produces changes in the red cell content and hemoglobin values of the blood somewhat analogous with those induced by chlorine and in entire accord with what might be anticipated by one with a knowledge of the alterations in blood concentration induced by chlorpicrin. (See Figures 39, 40 and 41.) Typical data may be found in Table XXXII. For additional experiments see Appendix to Chapter VII, page 291.

The data for white cell counts of the blood are incomplete in that no determinations were made with either phosgene or chlorpicrin. However, a fairly extensive study was made with chlorine, the results of which follow.

Leucocyte counts were made on animals gassed with chlorine in concentrations from 0.33 mgm. to 6.32 mgm. per liter, with variable intermediate concentrations.

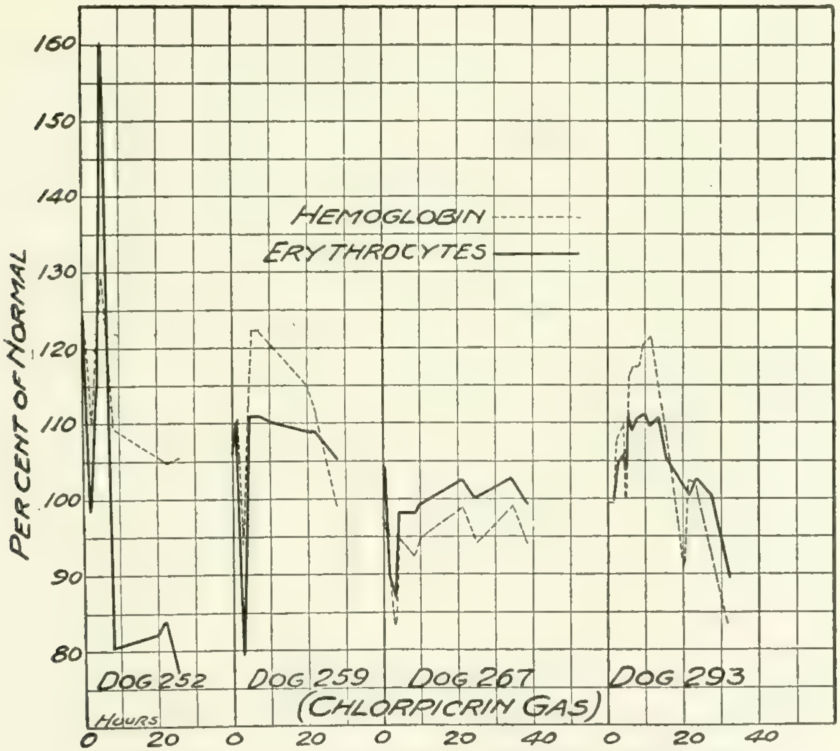

Fig. 39. COMPARISON OF ERYTHROCYTES AND HEMOGLOBIN CONTENT OF BLOOD.

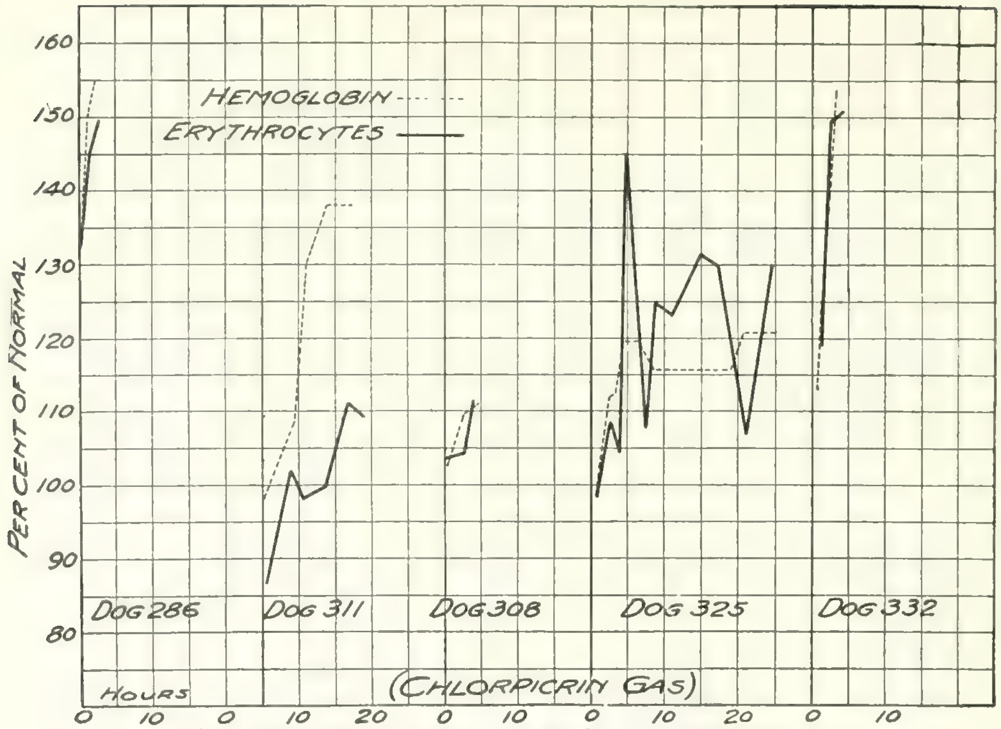

Fig. 40 Comparison of Erythrocytes and Hemoglobin Content of Blood

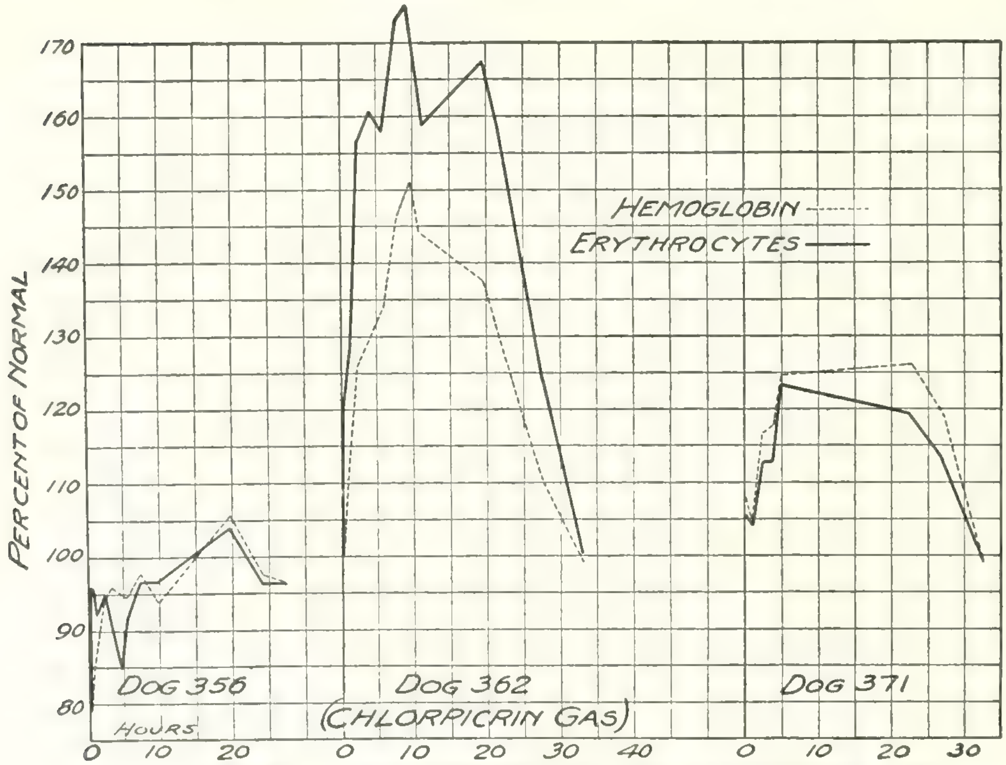

Fig. 41. Comparison of Erythrocytes and Hemoglobin Content of Blood

TABLE XXXI

Erythrocyte Count in Blood of Dogs Gassed with Phosgene

Dog No.	*Gas Conc. parts per million*	*Before Gassing*	*Hours after Gassing*										*Fate of Animal*
			1–2	*3–4*	*5–6*	*7–8*	*9–10*	*13–16*	*19–22*	*23–24*	*25–28*	*30–*	*45–50*	
			Thousand Erythrocytes per cu. mm.											
496	63	4900	4600		4400			6000			5800		5050	Recovered
486	69	4760	4250	4570			5770	5670		*				Died
361	71	4712	3600		3968				6420*					Died
383	77	5670	4850	5825						6070	6200	*		Died
386	78	5750	4100					*						Died
395	79	5500	4760		6150					7360	7560	*		Died
426	79	4960						6450	6300*					Died
434	79	5170	4400		4870		4820	5400		5560	5350	5250	5000	Recovered
406	114	5700	5600	5950		6170	6860			11525	*			Died

* Time animal died.

TABLE XXXII

Comparison of the Erythrocytes and Hemoglobin Content of Blood

Chlorpicrin Gas

		Before Gassing				*After Gassing*			
Dog No.	*Date*	*Red Count*	*Hemoglobin*	*Gassed mgm. Per liter*	*Date Gassed*	*Red Count*	*Hemoglobin*	*Red Count Per cent*	*Hemoglobin Per cent*
252	10/20	7,808,000	94	.603	10/21	6,808,000			
	10/21	7,846,000			1 hr.	9,792,000	117	124	124
					2 "	8,128,000	105	97	111
		7,827,000			3 "	8,480,000	104	108	110
					4 "	8,992,000	107	114	114
					5 "	12,640,000	122	161	130
					8 "	6,320,000	103	81	109
					20 "	6,400,000	94	83	100
					22 "	6,480,000	99	84	105
					26	6,160,000	100	78	106
259	10/22	6,480,000	94	.596	1 hr.	6,840,000	100	107	107
		6,240,000	94		2 "	7,040,000	104	110	111
					3 "	5,120,000	88	80	94
					4 "	6,960,000	106	109	113
		6,360,000			5 "	7,120,000	116	112	123
					6 "	7,120,000	116	112	123
					8 "	7,040,000	115	111	122
					20 "	6,960,000	108	109	115
					22 "	6,940,000	105	109	112
					27 "	6,740,000	95	106	99
267	10/23	6,800,000	99	.674	1 hr.	7,040,000	96	104	97
		6,740,000			2 "	6,120,000	93	91	94
					3 "	6,000,000	83	88	84
		6,770,000			4 "	6,640,000	94	98	95
					8 "	6,648,000	92	98	93
					10 "	6,720,000	94	99	95
					22 "	6,960,000	98	103	99
					26 "	6,880,000	93	101	94
					34 "	6,940,000	98	103	99
					38 "	6,720,000	93	99	94

Low Concentrations

Animals gassed at extremely low concentrations (i. e., 0.18 mgm. per liter) exhibit a slight leucocytosis within 3 to 5 hours after gassing, which is followed by a return to normal almost immediately, except in cases where the animal develops a slight bronchitis. The counts were not followed beyond the third day subsequent to exposure to the gas. (Cf. Table XXXIII.)

Moderate Concentrations

A detailed study of the changes in leucocytes was made in a series of six dogs gassed at concentrations varying from 1.23–2.21 mgm. per liter. Three of the dogs died, showing upon autopsy different stages of pneumonia, while two survived passing through a stage indicating broncho-pneumonia, considerable time elapsing before their full recovery.

TABLE XXXIII

The Influence of Chlorine Gassing upon the Leucocyte Count

Dog No. 525

Gas concentration—0.17 mgm. per liter

Hours	*Leucocytes*	*Percentage normal*
Normal	16,000	100
¼	10,500	66
¾	9,700	61
1¼	14,000	87
2	18,800	117
4	25,300	158
4½	22,200	139
5½	22,200	139
6¼	23,000	144
7	23,600	147
23	24,000	150
24	23,000	144
25	22,500	140
25½	25,000	156
27¾	14,800	93
28¼	14,800	93
28¾	17,600	110
29½	17,600	110

Animal developed a slight bronchitis

Dog No. 526

Gas concentration—0.18 mgm. per liter

Hours	*Leucocytes*	*Percentage normal*
Normal	6,000	100
¼	6,400	106
½	4,800	80
1¼	4,800	80
2¼	8,200	136
4¼	8,600	143
4¾	9,000	150
5⅓	9,800	163
6	10,880	182
7	12,000	200
9⅔	8,600	143
12½	7,000	117
24	6,000	100
25	7,700	128
26½	5,000	84

Recovered immediately

The extent of the leucocytosis varies greatly but shows a typical picture in any case. One dog (No. 527) showed *very few symptoms* and gave the same picture as a dog gassed at very low concentration, i. e., a slight leucocytosis and a return to normal the next day. (Table XXXIV.) The remaining dogs that recovered with pulmonary complications developed a moderate leucocytosis, which continued for several weeks, followed by a return to normal on complete recovery. (Table XXXV.)

The fatal cases in this series showed typical curves which correspond to the condition of animals gassed at very high concentrations. There was one type which developed an extreme leucocytosis followed by a fall in count before death (Table XXXVI), and another in which not even a moderate leucocytosis appeared. In the latter, autopsies revealed severe cases of purulent broncho-pneumonia. (Table XXXVII.) We may, therefore, assume that the development of continued moderate leucocytosis (about 200 per cent) is essential for the protection of the organism in cases where animals have been gassed at a moderately high concentration.

High Concentrations

The last series of animals were gassed at very high concentrations, far above the lethal dose. This procedure was followed in order to see if it were possible to diagnose a fatal case of chlorine poisoning from the leucocyte count. Four distinct types of curves were observed: (a) In one case, an extremely high leucocytosis was followed by death a few hours after gassing, and in another a gradual fall in count for several days, after which death resulted. (Table XXXVIII.) (b) A moderate leucocytosis followed by a sudden drop in count on the day after gassing. (Table XXXIX.) (c) A failure of the organism to develop leucocytosis, in which case death resulted in about three hours after gassing. (Table XL.) (d) A slow development of a leucocytosis followed by marked fluctuations in count, death occurring within 10 hours. (Table XLI.)

Differential Count

A partial study of the differential picture showed that leucocytosis was caused solely by an increase in polymorphonuclear cells, the lymphocytes and mononuclear cells playing no part. The eosinophile disappeared from the circulation for a short time several hours after gassing.

The data presented above may be restated from the standpoint of whether or not the dog recovers from the chlorine poisoning.

Dogs that recover show two types of curves: (a) after mild gassing, a slight leucocytosis (100 per cent) followed by quick return to normal; (b) after lethal concentrations of chlorine, a moderate leucocytosis (300 per cent) persisting for several weeks.

Dogs which exhibit the following leucocytotic condition have invariably died: (a) no leucocytosis; (b) an unstable fluctuation in the leucocyte count during the first few hours after gassing; (c) a moderate leucocytosis followed by a marked drop (acute and chronic cases); (d) an extreme leucocytosis during the first few hours after gassing.

TABLE XXXIV

The Influence of Chlorine Gassing upon the Leucocyte Count

Dog No. 527

Gas concentration—1.23 mgm. per liter

Hours	*Leucocytes*	*Percentage normal*
Normal	13,000	100
¼	16,000	123
¾	18,100	139
1¼	18,100	139
1⅔	18,100	139
3½	19,700	151
5	22,400	172
5¾	21,600	166
7	22,100	141
9½	22,000	170
11¾	19,800	152
23¼	18,200	140
24½	15,000	115
25½	15,000	115
28¼	13,200	100
29¾	13,600	100

TABLE XXXV

The Influence of Chlorine Gassing upon the Leucocyte Count

Dog No. 395A

Gas concentration—1.92 mgm. per liter

Time	*Leucocytes*	*Percentage normal*
Normal	6,500	100
10 min.	6,700	100
½ hr.	7,800	120
2	11,000	170
2½	11,800	180
4	22,000	340
5	20,200	310
7	25,200	387
10	29,840	460
11	32,000	490
23	29,600	450
24	31,000	470
29	22,400	345
35	22,400	345
46	33,800	520
48	27,300	420
59	33,000	510
3 days (72 hrs.)	34,000	520
" (83 ")	49,000	750
4 days	41,000	630
5 "	44,300	670
6 "	37,600	580
7 "	21,600	330
10 "	28,000	430
23 "	31,200	480
31 "	12,800	197
59 "	9,600	140

TABLE XXXV (Continued)

Dog No. 524

Gas concentration—1.26 mgm. per liter

Time	*Leucocytes*	*Percentage normal*
Normal	18,000	100
10 min.	18,000	100
40 min.	21,000	114
1¼ hrs.	24,800	140
1¾	26,500	145
2¼	29,000	160
5	30,000	165
5½	31,400	175
6	33,600	185
7	36,400	200
12	32,800	188
23	32,800	188
24	30,000	165
25½	23,200	129
26	28,500	160
28½	23,400	130
30½	28,400	157
31	32,000	185
47	23,200	130
51½	23,800	130
72	33,800	190
74	33,600	190
78½	27,360	152
4 days (95 hrs.)	12,800	71
5 " (128 ")	9,800	55
7 "	24,800	138
8 " fully recovered	17,000	95
9 "	27,680	153
10 " bronchitis	25,800	143
11 " "	24,000	140
14 " "	32,400	200

Developed pulmonary complications after returning to normal

TABLE XXXVI

The Influence of Chlorine Gassing upon the Leucocyte Count

Dog No. 380

Gas concentration—1.99 mgm. per liter

Hours	*Leucocytes*	*Percentage normal*
Normal	10,300	100
40 min.	8,800	86
1½ hrs.	19,800	198
3	33,600	320
5	43,400	410
6	53,300	520
10	48,800	470
23	35,600	345
24	43,600	420
28	42,600	410
35	25,800	250 (sudden drop)
35—Died		

Early pneumonia, moderate edema, chicken fat clot.

TABLE XXXVII

The Influence of Chlorine Gassing upon the Leucocyte Count

Dog No. 521

Gas concentration—1.29 mgm. per liter

Hours	*Leucocytes*	*Percentage normal*
Normal	11,200	100
1	9,000	80
2	22,000	200
3	16,000	143
4½	16,800	145
6	14,800	133
7	17,400	155
12	16,000	143
24	18,000	160
25	14,500	130
27	15,600	140
30	16,500	147
31	21,360	190
37	20,960	187
55	16,900	150
72	6,000	54
74	6,400	55
76—Died		

Lungs show dark grayish yellowish elevated areas on surface. Areas firm on section are gray, granular and consolidated. Purulent bronchitis. Whole heart dilated, chicken fat clot.

TABLE XXXVII (Continued)

Dog No. 389

Gas concentration—1.83 mgm. per liter

Hours	*Leucocytes*	*Percentage normal*
Normal	10,000	100
¼	10,000	100
½	7,000	70
1	10,000	100
1¼	8,000	80
1½	7,000	70
2	12,500	125
2½	14,200	142
3½	11,200	112
6	16,400	164
7¾	16,000	160
24½	13,760	137
26	7,600	76
28	8,400	84
30	10,900	109
33	11,300	113
45	12,600	126
47	12,000	120

70—Found dead.

Lungs show extreme broncho-pneumonia; also numerous white opaque areas. Emphysema and atalectasis marked.

TABLE XXXVIII

THE INFLUENCE OF CHLORINE GASSING UPON THE LEUCOCYTE COUNT

Dog No. 489

Gas concentration—3.24 mgm. per liter for 40 minutes

Hours	*Leucocytes*	*Percentage normal*
Normal	14,000	100
½	19,800	140
1½	25,600	183
2	26,500	190
2½	29,000	210
3½	33,400	240
4	43,200	310
4¾	40,000	290
6	50,400	360
6½	62,600	450

7½—Died

Extreme leucocytosis. Marked edema, emphysema, slight congestion, dilated heart.

TABLE XXXVIII (Continued)

Dog No. 459

Gas concentration—4.40 mgm. per liter

Hours	*Leucocytes*	*Percentage normal*
Normal	15,000	100
½	15,200	100
¾	21,000	140
1	21,600	145
1½	23,200	155
2	26,560	170
4	29,600	200
4½	34,600	230
6	38,900	260
6½	43,600	290
7½	49,000	330
11½	50,800	340
12½	56,400	370
24	48,200	320
25½	51,200	340
30	59,800	400
32	40,600	270
35	48,600	320
47	38,000	250
54	36,000	240
57	34,400	230
71	15,000	100
71—Died		

Extreme leucocytosis with a somewhat rapid drop. Marked emphysema in upper lappets of lungs, lower lobes firm and beefy, marked consolidation. Bronchi filled with purulent exudate.

TABLE XXXIX

The Influence of Chlorine Gassing upon the Leucocyte Count

Dog No. 414

Gas concentration—3.10 mgm. per liter

Time	*Leucocytes*	*Percentage normal*
Normal	13,600	100
20 min.	10,000	74
½ hr.	11,600	85
1	11,600	85
2	18,500	136
2¾	23,800	175
3½	25,300	186
5	30,500	225
6	27,400	200
6½	32,200	230
8	34,400	250
10	33,600	250
12	35,200	260
24	22,000	162 (drop)
28	19,400	140
29	18,560	140
30½	19,000	140
30½—Died		

Marked edema and extreme congestion. Right heart slightly dilated.

Dog No. 439

Gas concentration—3.01 mgm. per liter

Hours	*Leucocytes*	*Percentage normal*
Normal	12,000	100
1	14,500	120
2	23,600	200
3	23,400	200
5	22,000	185
5½	33,400	220
7	35,200	300
11	26,600	220
23	4,500	37
24	3,600	30
28	1,600	13
30	300	3
31	1,000	8
32—Died		

TABLE XL

The Influence of Chlorine Gassing upon the Leucocyte Count

Dog No. 507

Gas concentration—3.36 mgm. per liter for ¾ hour

Hours	*Leucocytes*	*Percentage normal*
Normal	23,300	100
½	22,800	99
1	23,400	100
1½	27,200	115
3	22,000	96
3—Died		

TABLE XLI

The Influence of Chlorine Gassing upon the Leucocyte Count

Dog No. 479

Gas concentration—6.52 mgm. per liter

Hours	*Fluctuating curve Leucocytes*	*Percentage normal*
Normal	11,800	100
1	13,800	117
2	20,900	180
3	26,000	220
3½	13,600	115
4	24,000	200
5	23,000	195
6½	30,160	270
7	22,960	195
8—Died		

Marked edema and congestion. Right heart dilated.

TABLE XLI (Continued)

Dog No. 508

Gas concentration—3.28 mgm. per liter for ¾ hour

Hours	*Fluctuating curve* *Leucocytes*	*Percentage normal*
Normal	13,800	100
¼	10,800	78
½	17,000	125
1	14,800	107
1½	16,800	125
2	26,400	190
2½	22,960	165
2¾	27,200	200
3	21,200	155
3½	15,800	115
4	23,800	170
4¼	23,000	165
5	6,400	47
5—Died		

CHAPTER VIII

THE DEVELOPMENT OF PULMONARY EDEMA

Pulmonary edema is a very prominent feature of the effects of the lethal war gases on the animal organism. To its development attaches great significance in any explanation of the detrimental influence of a gas. Equally important is a consideration of the subject when attempts are made to define the cause of death in the circumstances under discussion.

The lethal war gases are all substances eminently irritant to living tissues and it must be accepted that the irritation produced by a gas is the initial step in the development of edema. In response to the first irritative stimulus tissue fluid finds its way to the injured area in an apparent attempt toward repair or alleviation of the injury. It is conceivable that if damage to the tissue is only slight such a procedure would result in the passage to the damaged area of only a small quantity of tissue fluid. According to this view the degree of response with respect to the local deposition of tissue fluid would be in direct ratio to the extent of injury. On the other hand, it is equally plausible to assume that this reaction may reach a breaking point at a certain degree of stimulation whereby the whole mechanism governing the exudation of tissue fluid is thrown out of control so that the response to the stimulation becomes overwhelming. Under these conditions a reaction which in its initial function may be regarded as beneficent eventually becomes a direct menace to continued existence on the part of the mechanism as a whole merely by interposing mechanical difficulties in the way of respiration and circulation.

It is not proposed in this place to discuss in detail the underlying principles of edema production. Rather an endeavor will be made to correlate so far as possible various observations that have been carried through in this investigation with the development of pulmonary edema. At this time, therefore, attention is called to the development of edema of the lungs in its time relations; the correlation of pulmonary edema with changes in blood concentration; the association of edema with chloride and fluid exchange in tissues and the blood, and the relation of edema to vascular permeability.

A. *Edema and Its Time Relations.*

In connection with the determination of the toxicity of phosgene for dogs a relationship was observed between the time of death and the concentration of the gas to which the animal has been exposed. In general the greater the concentration the sooner the occurrence of death. Accordingly in this report attention was confined to a concentration somewhat below the lethal (70 parts per million; 0.31 mgm. per liter), and to one somewhat above the lethal concentration (90 parts per million; 0.40 mgm. per liter). In all cases a standard time of exposure for 30 minutes was used.

The dogs were killed by strychnine injection at intervals after exposure and samples of tissue were taken from different parts of the lung. An effort was made to secure as composite a sample as possible and to reduce to a minimum the loss of exuding edema fluid during sampling. There was always slight loss, particularly with very wet lungs, so that the results may not be quite as accurate as when the entire lung is dried. The error, however, is negative rather than positive and the degree is not sufficient to compensate for the difficulties of analysis by the latter method. The samples for the determination of the total solids in the blood were drawn at regular intervals by needle from the jugular vein. All samples were carefully dried to constant weight at 105 degrees.

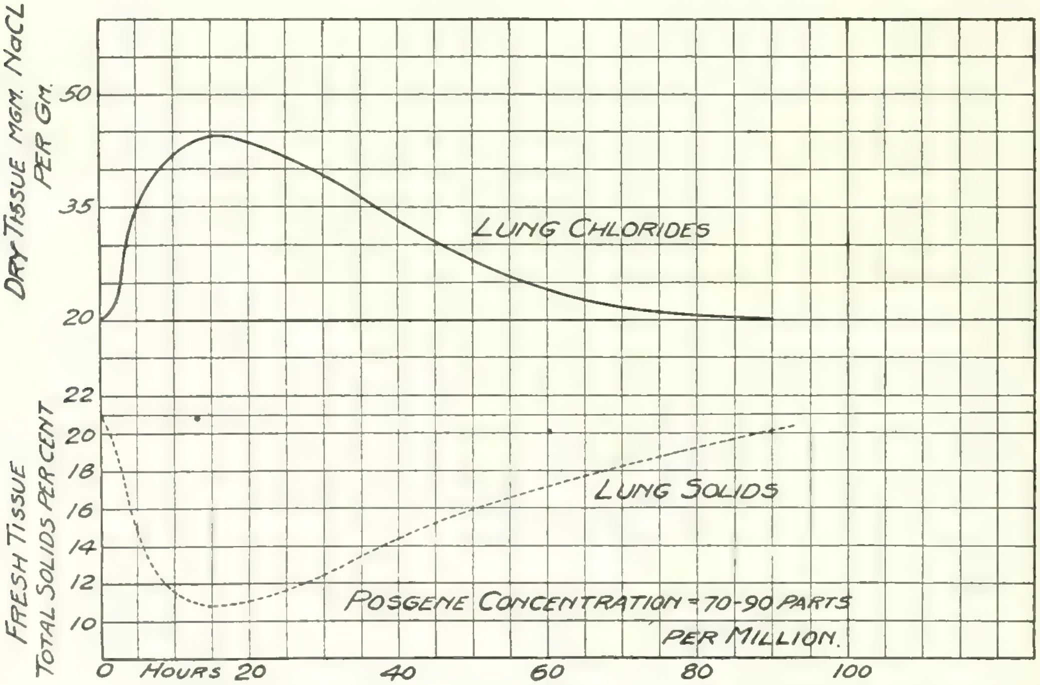

FIG. 42 CHANGES IN THE CHLORIDES AND TOTAL SOLIDS OF THE LUNGS AFTER PHOSGENE POISONING.

The total solids of the lung (Tables XLII and XLIII and Figs. 42 and 43) show a rapid and extreme decrease indicating the production of an intense edema of the most marked type. This is most noticeable in dogs No. 481 and No. 479 killed at 8 and 9½ hours after gassing. In these two animals the total solids of the lung have fallen to 8.6 and 7.1 per cent from a normal value of about 21.4 per cent. Assuming that the decrease in total solids was due to the influx of water alone into the lung these values would represent the influx of 150 and 200 cubic centimeters respectively of water per 100 grams of original tissue, a truly enormous increase. In view of the fact that the edema fluid contains most of the constituents of plasma and that no allowance is made for these, the actual inflow would, therefore, be greater than that here calculated.

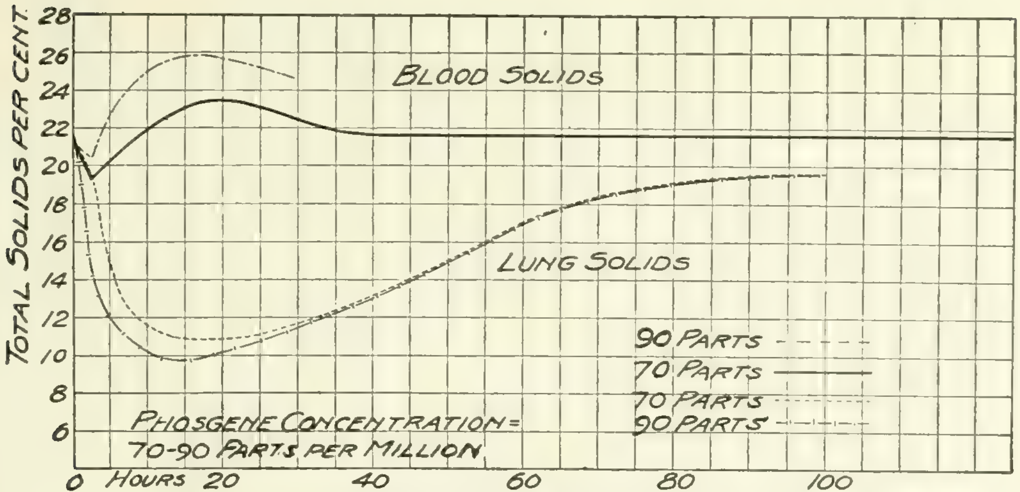

Fig. 43. CHANGES IN THE TOTAL SOLIDS OF THE BLOOD AND LUNGS AFTER PHOSGENE POISONING.

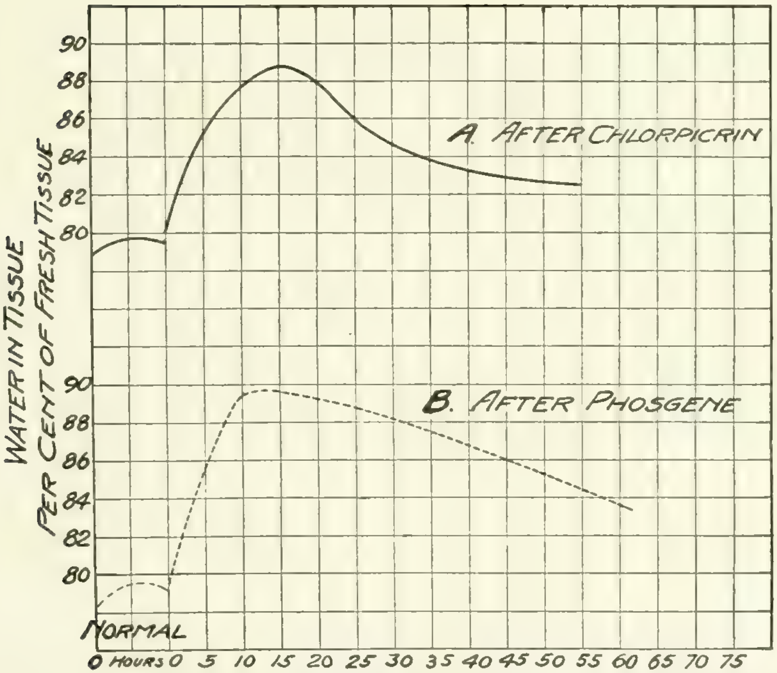

Fig. 44. WATER CONTENT OF LUNG TISSUE AFTER CHLORPICRIN AND PHOSGENE POISONING

TABLE XLII

Analyses of Lungs after Phosgene Gassing

Gas concentration 70 parts per million (0.30 mgm. per liter)

Dog No.	*Hours after gassing*	*Fate of animal*	*Chloride Dry tissue mgm. per gm.*	*Total Solids Fresh tissue per cent*
Normal		Killed	19.8	21.4
P457	2.0	"	22.8	16.3
P456	3.0	"	23.8	19.0
P455	5.0	"	29.8	15.6
P408	5.0	"	31.1	15.2
P275	5.0	"	21.7	16.3
P173	5.5	Died	41.2	11.4
P452	6.0	Killed	37.5	12.6
P400	8.0	"	37.9	13.4
P463	9.0	"	40.2	
P461	9.5	"	39.0	12.9
P462	10.0	"	38.1	11.4
P460	11.0	"	36.9	11.4
P124	12.0	Died	41.5	11.5
P349	12.0	"	33.6	11.5
P431	13.0	Killed		11.2
P399	19.0	"	41.5	12.2
P393	19.5	"	41.0	10.2
P385	20.0	"	43.8	12.9
P398	22.0	"	43.4	11.7
P384	22.0	"	52.0	10.9
P528	27.0	"	39.3	12.0
P532	27.0	"	45.4	12.3
P350	28.0	Died	40.6	10.9
P531	28.0	Killed	41.1	10.9
P368	36.0	Died	29.1	13.8
P482	48.0	Killed	41.0	11.8
P516	51.0	"	29.8	15.6
P505	96.0	"	25.5	15.7

TABLE XLIII

Analyses of Lungs after Phosgene Gassing

Gas concentration 90 parts per million (0.39 mgm. per liter)

Dog No.	*Hours after gassing*	*Fate of animal*	*Chloride Dry tissue mgm. per gm.*	*Total Solids Fresh tissue per cent*
Normal		Killed	19.8	21.4
P473	1.0	"	21.3	19.9
P472	1.5	"	35.2	17.9
P276	2.5	"	30.9	15.1
P471	3.5	"	42.8	13.1
P470	4.0	"	40.1	13.4
P407	6.0	"	41.6	12.9
P465	6.5	"	28.5	16.3
P138	6.5	Died	29.8	13.4
P464	7.0	Killed	38.2	12.5
P481	8.0	"	65.6	8.6
P480	9.0	"	59.2	10.6
P479	9.5	"	45.9	7.1
P323	10.0	Died	36.4	10.7
P139	10.5	"	37.3	12.1
P351	11.0	"	32.9	12.0
P478	11.0	Killed	51.9	11.0
P476	14.0	"	48.8	11.3
P474	18.0	"	38.6	13.2
P140	22.5	Died	54.0	9.0
P171	24.0	"	36.4	12.6
P322	24.0	"	39.1	11.4
P382	25.0	Killed	42.4	12.2
P257	30.0	"	33.6	11.3
P515	51.0	"	24.8	16.6
P513	52.0	"	27.0	15.6
P284	144.0	"	13.3	21.6

TABLE XLIV

Analyses of Tissues after Chlorine Gassing

Dog No.	Gas Conc. for 30 min.	Hours after gassing	Lung		Muscle		Liver		Spleen	
			Chloride (Dry tissue)	*Total Solids (Fresh tissue)*	*Chloride (Dry tissue)*	*Total Solids (Fresh tissue)*	*Chloride (Dry tissue)*	*Total Solids (Fresh tissue)*	*Chloride (Dry tissue)*	*Total Solids (Fresh tissue)*
	mgm. per liter		*mgm. per gm.*	*per cent*	*mgm. per gm.*	*per cent*	*mgm. per gm.*	*per cent*	*mgm. per gm.*	*per cent*
(Average 3 normal dogs)	0	0	18.7	22.5	3.9	24.3	12.4	23.5	11.8	21.8
407	2.59	0.5	27.0	17.8						
408	2.58	1	42.0	13.0						
4	2.85	2	37.5	14.3	4.2	24.2	7.4	28.3	12.3	21.5
29	2.86	3	41.5	11.6	3.7	22.9	8.6	26.8		15.1
24	3.38	5	35.6	12.0	3.7	24.4	8.6	20.8	12.8	21.1
2	1.45	22	32.3	14.0	4.6	23.5	10.6	22.2	13.2	19.6
26	2.93	24	43.8	11.2	3.2	25.5	8.2	26.1		22.2
30	3.00	28	23.3	16.2	3.8		9.2	23.4		20.1
43	2.51	36	28.6	17.2	3.9		10.6	25.6		16.1
71	2.77	45	22.6	17.4						
47	2.54	57	25.8	17.0	2.8	27.8	10.8	25.8	11.4	21.1
69	1.64	60	24.1	16.3						
50	2.22	85	25.7	17.9	3.8	26.5	8.4	27.1		21.2
33	1.97	130	20.6	17.2		23.4	12.3	22.0	13.3	19.9
40	2.12	140	17.2	18.6	3.3	25.9	11.1	23.5		
51	2.42	312	19.0	17.9						

TABLE XLV

Solids in Fresh Tissue

Chlorpicrin Dogs

Dog No.	*Hours after gassing*	*Lung per cent*	*Liver per cent*	*Muscle per cent*
387	1½	12.5	27.5	24.8
386	3	14.8	27.6	27.3
374	3	12.7	30.5	26.6
407 d	3½	18.5	26.3	30.3
332 d	4	12.2	25.4	24.8
385	4½	15.95	26.3	22.5
331	4½	15.2	27.3	29.9
200	5	16.5	27.6	26.6
220	5	lost	lost	26.0
383	5	12.8	29.1	22.0
199	6	21.2	26.0	27.8
289	6	11.0	26.8	lost
388	6	10.44	26.0	21.5
187 d	6½	16.0	25.7	24.5
227 d	7	16.3	25.7	27.0
213 d	7¼	lost	27.4	25.0
191 d	8	15.2	26.1	26.0
178	9	13.3	26.5	33.4
408 d	9	13.9	26.5	26.0
243 d	11	12.9	24.5	lost
404 d	14	12.8	27.1	28.1
214	14½	11.66	25.2	27.8
420	15	12.1	27.8	26.8
422	15	12.1	26.6	24.4
177 d	16½	11.6	27.0	29.3
415	18½	12.1	28.8	27.2
402	19	13.7	27.8	26.4
394	21	12.7	29.3	26.7
414	21	10.8	26.3	25.5
411	21½	13.8	25.4	24.1
212	23	13.96	27.6	27.35
211	24	15.75	27.6	26.4
201	24½	14.6	25.6	26.8
249	25½	15.5	26.4	25.7
180	26	14.1	26.2	22.1
193 d	30	17.7	23.9	26.8
186 d	30	16.3	23.9	23.6
325	51	16.1	24.0	24.1
205	3¼ days	15.85	28.6	23.3
206	3¼ days	14.6	27.7	27.7

Note: The letter "d" following certain dog numbers above, indicates that in those instances, the samples were taken from dogs dying from the effects of gassing, and not killed or anæsthetized.

The experimental series is small in view of the variation among individual animals, but a careful examination of either the data or the curves (for example, Fig. 43) shows that in general the animals gassed at a concentration of 90 parts per million (0.40 mgm. per liter) show a given total solid content 4 to 6 hours before those gassed at a concentration of 70 parts per million (0.31 mgm. per liter). At a given time the total solid content is 1½ to 2½ per cent lower in the dog gassed at the higher concentration.

A maximum degree of change is present in both sets of analytical results from 10 to 25 hours after gassing. After this time there is a more gradual return to the normal lung condition.

Analysis of lungs of dogs subjected to chlorine gas shows an immediate influx of water to a marked degree (see Table XLIV). The water of the lungs gradually subsides if the animal survives a sufficiently long period.

With chlorpicrin (see Table XLV and Fig. 44) the water content changes of the lungs are very significant and for the sake of comparison these changes after phosgene poisoning are included.

The changes in the lung indicate the rapid production of a marked pulmonary edema and its gradual subsidence with all three gases. The rapidity of the production of this edema depends in part at least upon the concentration of the gas employed and there are indications that there is a direct relationship between gas concentration and the degree of edema.

B. *Edema and Blood Concentration.*

In Fig. 43, page 87, a comparison is made between the rate and extent of edema production and the changes in the blood solids in phosgene poisoning. The data for the blood solids have been taken from Chapter VI, pages 42 ff. (see also Appendix to Chapter VI, page 264). The courses of the two processes are fairly synchronous, the development of edema corresponding with a fair degree of accuracy to the concentration of the blood. The only explanation for the initial dilution of the blood is that at first fluid passes more rapidly into the blood than it can pass from the blood into the lungs. In general the blood returns more rapidly to the normal level than is true for the lungs. In the latter instance, however, there is a possibility of interfering secondary factors, such as pneumonia, which may complicate the matter.

From the data in Table XLIV, and Table XXVII, page 57, Chapter VI, for fluid changes in the lungs, and blood concentration alterations respectively, what has been concluded relative to phosgene applies equally well to chlorine. To even a greater extent is this true for chlorpicrin (see Table XLV and Fig. 44, pages 91 and 87).

From the data represented it may be concluded that for the production of edema of the lungs induced by all three gases, fluid is drawn from the blood. Moreover, since it has been shown (Chapter VI) that the hemoglobin and total solids have similar types of curves *the estimation of hemoglobin may be employed to follow the course of blood concentration and hence in general to act as a criterion of the development, or stage, of pulmonary edema.*

C. *Edema and Changes in Salt Content of Blood and Lungs.*

In any study of the production of edema the question of possible disturbances in the salt relationships is at once raised. In an effort to secure a partial elucidation of this problem a study has been made of the chloride content of the blood and lungs of dogs gassed with phosgene. No study was made in this connection with chlorpicrin.

In this investigation attention was confined at first to concentrations of 90 and 70 parts of phosgene per million of air, *i.e.*, slightly above and slightly below the lethal concentration. Blood chlorides were estimated by the method of McLean and Van Slyke. The chloride content of the lungs was determined in the dried tissue used for the study of the total solids. The method of analysis was a modification of the McLean and Van Slyke procedure.

In normal starving dogs the chloride content of the blood plasma is approximately constant from day to day, but there is a wide variation among individuals. In order to eliminate disturbing effects of this factor in the average of a small experimental series the results (see Tables XLVa and XLVb) have been expressed in terms of the percentage of the normal value as well as in terms of mgm. of NaCl per cubic centimeter. Since it was found that the plasma and whole blood chlorides underwent parallel changes, only the plasma chlorides were determined. More uniform alterations were obtained when the animals were starved for 48 hours before gassing than when inanition was for a period of 24 hours only. Owing to the small experimental series no distinction was made between animals starved for different times or gassed at the different concentrations, the discussion being confined to the average of the entire experimental series. The results of these observations are expressed graphically in Fig. 45.

There is practically no change in the plasma chlorides during the first four hours after gassing. Between the fifth and sixth hour, however, there is a marked and rapid drop in the blood chlorides. This drop reaches a minimum at about the 20th hour and from then on the blood chlorides show a gradual increase during the first two days after gassing until about the 50th hour when they gradually return to normal. During the period of blood dilution there is practically no change in the blood chlorides, indicating that the diluting fluid must be isotonic with blood plasma. The blood chlorides, however, drop sharply at about the time when the concentration of the blood first becomes marked.

It has already been shown that blood concentration is due to the passage of fluid from the blood into the lungs. Examination of the lungs furthermore shows a rapid increase in the chloride content following gassing (Figs. 42 and 46, and Tables XLII and XLIII, pages 86 and 96, and 88 and 89). There is a latent period in this inflow of chlorides extending over the first 3 or 4 hours followed by a very rapid increase. Maximum values are obtained by the tenth hour and are maintained during the rest of the first day following gassing. After this period the chlorides leave the lung and the chloride content gradually returns to normal. Complete data are not available, but the process of chloride disappearance from the lung is well advanced by the 50th hour and the normal must be regained soon after.

From these results it becomes evident that the entrance of chlorides into the lungs determines the blood values. The amount of blood chlorides (see Fig. 45) is unaltered until retention develops in the lungs. Following the development of this lung condition the blood chlorides drop to a minimal value and are so maintained until the 50th hour, when a return to normal commences. This corresponds to the passage of the acute pulmonary condition.

In animals dying from acute edema and autopsied immediately, samples of the pulmonary exudate can be obtained by removal of the entire lungs and collection of uncontaminated fluid as it runs from the trachea. The fluid collected in this way is clear, straw colored, and occasionally contains a few erythrocytes. It clots on standing. Determina-

TABLE XLVA

Chloride Content of Blood Plasma after Phosgene Gassing

Chlorides°

Dog No.	Gas Conc.	Before Gassing	Hours after Exposure 1–2	3–4	5–6	7–8	9–10	11–15	16–20	21–25	26–30	31–40	41–50	51–60	61–75	
166[1]	64		100	104	100					97	97	102	108	103	107	Recovered
127[1]	65	100	96	86	84	77	90	85		87	75	75	72	90*		Died
126[1]	65	100	95	87	91				93	81	76	72	80	81	81	Recovered
124[1]	67	100	101	102	100		91	*								Died
199[1]	67	100	99	97		105		94		98	98	93	92	99	99	Recovered
350[2]	67	100		97		100		100	97	101	96*					Died
123[1]	69	100	99	92		100			91	96	101		86	82	89	Recovered
368[2]	69	100	97		95		95	94	93	86	94	*				Died
428[2]	71	100	103		99		99	101	104	100	104		97	99	104	Recovered
431[2]	71	100	98		97		96	100*								Died
349[2]	72	100		106		100		*								Died
429[2]	74	100	94		90		86	88	91	93	93		93	93	94	Recovered
206[1]	75	100	103			94			95	90	96		91	87	90	Recovered
367[2]	84	100		94		*										Died
323[2]	86	100	97		84		95*									Died
322[2]	87	100	98		98		84	90	85	88*						Died
139[1]	88	100	92		97		*									Died
140[1]	88	100	108	111	95		115	108		107*						Died
351[2]	89	100	96		96		*									Died
284[1]	91	100		96	96	95				86	86	86	88	87	88	Recovered
257[1]	93	100	102	110							100*					Died
Average		100	99	98	95	96	94.5	95.5	93.5	93.0	93.0		90.0	91.5	94.0	
Normal Animals not gassed.																
275[2]		100	92							105		97	96	98	97	
276[2]		100	94		106			106		108	103		104	106	105	
Average		100	93		**106**			**106**		**106**	**103**	**97**	**100**	**102**	**101**	

° Expressed as percentages.

[1] Starved 24 hours before gassing.

[2] Starved 48 hours before gassing.

* Time of Death.

TABLE XLVB

Chloride Content of Blood Plasma after Phosgene Gassing

Chlorides °

Dog	*Gas*	*Before*	*Hours after Exposure*													
No.	*Conc.*	*Gassing*	*1–2*	*3–4*	*5–6*	*7–8*	*9–10*	*11–15*	*16–20*	*21–25*	*26–30*	*31–40*	*41–50*	*51–60*	*61–75*	
166^{1}	64		5.82	6.05	5.81					5.62	5.62	5.94	6.28	5.99	6.22	Recovered
127^{1}	65	5.66	5.46	4.85	4.76	4.35	5.07	4.80		4.90	4.22	4.06	5.08	5.08*		Died
126^{1}	65	6.28	5.98	5.47	5.70				5.82	5.10	4.77	4.50	5.01	5.08	5.03	Recovered
124^{1}	67	5.70	5.78	5.80	5.70		5.18	*								Died
199^{1}	67	5.54	5.46	5.38		5.82		5.20		5.45	5.45	5.15	5.08	5.51	5.51	Recovered
350^{2}	67	6.71	6.48		6.67			6.68	6.50	6.78	6.46*					Died
123^{1}	69	6.10	6.02	5.62		6.10			5.56	5.82	6.20		5.22	5.00	5.40	Recovered
368^{2}	69	6.72	6.53		6.40		6.43	6.34	6.26	5.77	6.31	*				Died
428^{2}	71	6.31	6.48		6.27		6.27	6.43	6.60	6.28	6.60		6.10	6.25	6.64	Recovered
431^{2}	71	6.40	6.25		6.22		6.12	6.43*								Died
349^{2}	72	6.22		6.64		6.26		*								Died
429^{2}	74	6.72	6.31		6.02		5.75	5.93	6.12	6.25	6.22		6.22	6.22	6.31	Recovered
206^{1}	75	5.85	6.00			5.46			5.56	5.23	5.61		5.30	5.08	5.24	Recovered
367^{2}	84	7.01		6.60		*										Died
323^{2}	86	6.31	6.10		5.30		6.02*									Died
322^{2}	87	6.50	6.40		6.40		5.42	5.85	5.51	5.72*						Died
139^{1}	88	5.93	5.48		5.77		*									Died
140^{1}	88	5.93	6.44	6.60	5.06		6.86	6.40		6.37*						Died
351^{2}	89	6.72	6.48		6.44		*									Died
284^{1}	91	5.45		5.23	5.25	5.20				4.70	4.66	4.72	4.82	4.72	4.84	Recovered
257^{1}	93	5.36	5.46	5.93							5.38*					Died
Average		6.17	6.04	5.88	5.86	5.70	5.90	6.00	5.98	5.69	5.63		5.34	5.45	5.66	
Normal Animals not gassed.																
275^{2}		6.25	5.70							6.56		6.06	6.00	6.10	5.98	
276^{2}		5.86	5.50		6.22			6.25		6.32	6.03		6.09	6.23	6.15	

° Expressed in mgm. NaCl per cubic centimeters.

[1] Starved 24 hours before gassing.

[2] Starved 48 hours before gassing.

* Time of Death.

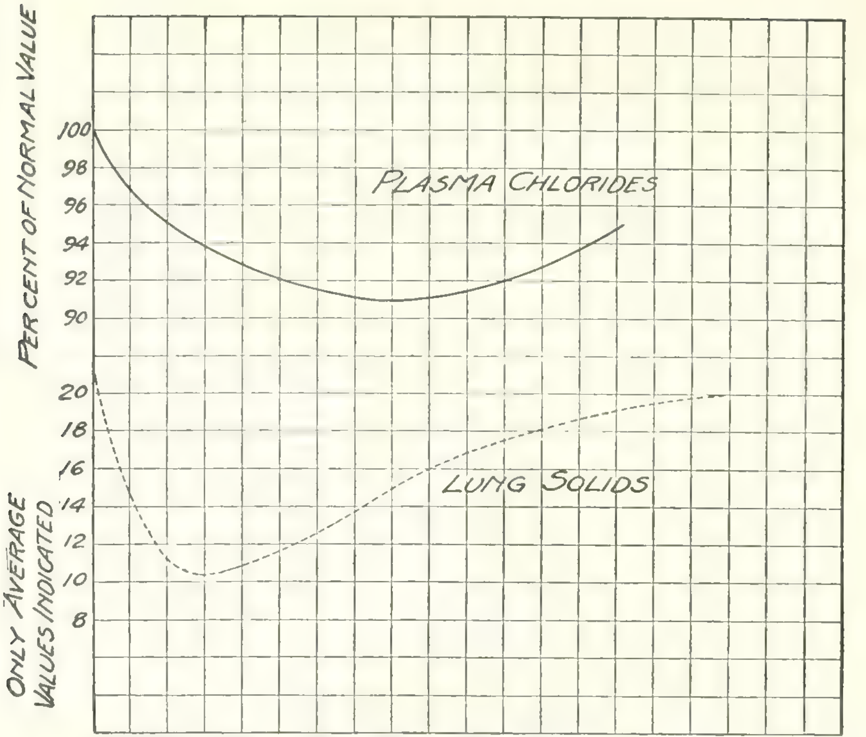

Fig. 45. RELATION BETWEEN CHANGES IN THE CHLORIDES OF BLOOD PLASMA AND LUNG SOLIDS AFTER PHOSGENE GASSING

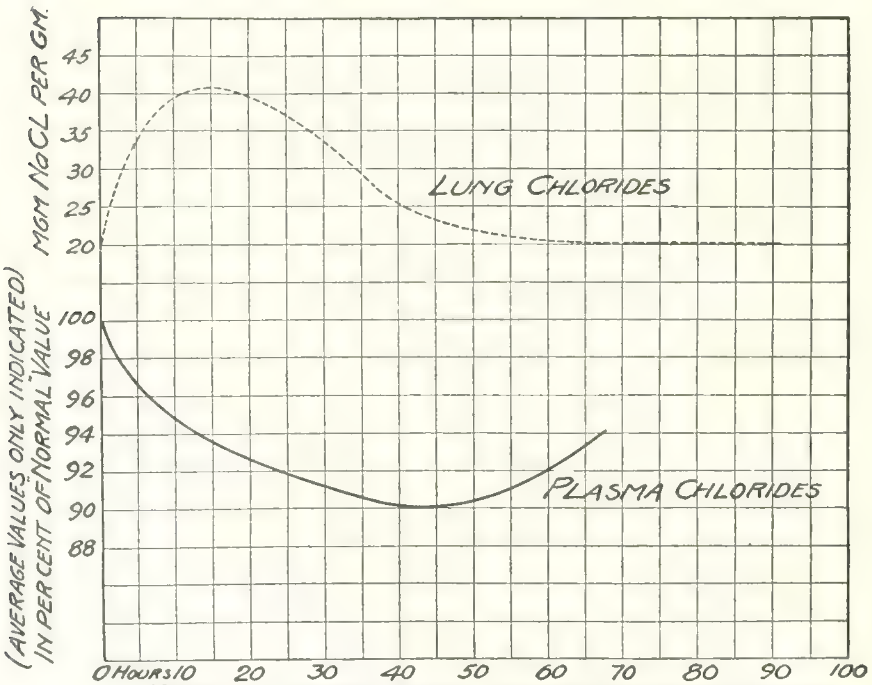

Fig. 46. CHANGES IN THE CHLORIDES OF LUNG TISSUES AND BLOOD PLASMA AFTER PHOSGENE GASSING.

tion of the chloride content of this fluid shows essentially the same value obtained from a simultaneous sample of blood plasma (see Table XLVI). This indicates that there is complete permeability of the lung capillaries for salts and that the pulmonary exudate and blood plasma are in complete equilibrium with reference to their salt content even if not exactly identical in composition.

TABLE XLVI

CHLORIDE CONTENT OF BLOOD PLASMA AND PULMONARY EXUDATE AFTER PHOSGENE GASSING

Dog No.	*Conc.*	*Time of Death* *Hours after exposure*	*Blood Plasma*	*Pulmonary Exudate*
			mgm. NaCl per cc.	
124	67	12	5.86	5.86
461	70	9.5	6.72	7.25
395	79	31	6.68	6.75
140	88	22.5	6.37	6.40
257	93	30	5.50	5.31
Average			6.22	6.31

The relationship between the blood and urine chlorides is not entirely clear. The high urinary excretion of chloride during the fourth to seventh hour after gassing shows no direct connection with either the blood or pulmonary changes. During the period of chloride retention in the lung and of low blood content the urine chlorides are well below normal and only increase on the third day after gassing, when the chlorides in the lung are liberated and the blood content again rises above the threshold of kidney excretion.

D. *Edema and Chlorides of Tissues other than the Lungs.*

With phosgene and chlorpicrin the data available are too incomplete to warrant a decisive inference relative to the part played by tissue chlorides in the production of pulmonary edema. Hence, these data are not included in the present discussion. With chlorine gassing, however, the liver and to a smaller extent the muscles show (see Table XLIV, page 90) a distinct tendency toward a decrease in the chloride content from 4 to 10 hours after gassing followed by a return to normal between 30 and 40 hours later. The change in the H_2O content of the liver is less marked than the chloride content, but the two changes tend to be parallel. It is realized that the evidence presented on this point is not entirely conclusive and it is included merely for the purpose of *indicating* the probable transport of chloride and fluid from the tissues to the blood.

E. *Edema and Total Solids of Tissues, other than the Lungs.*

A satisfactory explanation for the concentration of the blood during the production of edema is difficult. At least two hypotheses may be formulated: (a) Fluid is taken from the tissues to a maximum degree by the blood, whence it localizes in the lungs, the final blood concentration being caused by the inability of the tissues to supply further fluid demands made upon them by the blood. It is conceivable that extraction of fluid from a tissue, like muscle, can proceed to a limited extent only if normal processes are to obtain.

(b) The hypothesis is plausible that blood concentration is caused by mere extraction of fluid from the blood, the exit of fluid from the blood producing edema not only of the lungs but of other tissues also. If such a view is pertinent the degree of edema in tissues other than the lungs must be slight, inasmuch as there is no visible evidence of such a condition.

Analyses have been made of the total solid content of tissues of dogs gassed with chlorine, phosgene, and chlorpicrin. It is obvious that in order to obtain conclusive evidence in support of either of the above hypotheses a large number of determinations must be made owing to the individual variation of dogs with respect to the total solid content of the tissues. The data are insufficient to draw dogmatic conclusions, but are ample to indicate that the second hypothesis, namely, that there is a general edema of the tissues, does not hold. The evidence for this point of view may be found in Tables XLVII and XLVIII and Fig. 47 for phosgene; in Table XLV, page 91, and Fig. 48 for chlorpicrin, and in Table XLIV, page 90, for chlorine.

TABLE XLVII

SOLIDS IN FRESH TISSUE

Normal Dogs

Date	*Dog No.*	*Lung* *per cent*	*Liver* *per cent*	*Muscle* *per cent*
10/12	Normal 1	20.7	27.1	24.0
10/12	Normal 2	21.1	30.5	27.25
11/27	Normal 3	21.5	26.8	23.7
12/2	Normal 4	20.6	27.9	24.7
5/28		17.9		
2/14		23.4		
	Normal 44	19.0	23.5	24.3
	Average..........	20.6	27.2	24.8
		(7*)	(5*)	(5*)
	Maximum.........	23.4	30.5	27.25
	Minimum.........	17.9	23.5	23.7

* Figure in parenthesis indicates the number of individuals from which the average is computed.

From these tables and figures it is quite evident that with phosgene and chlorpicrin the liver does not lose water during the development of edema. With chlorine, however, a slight loss of H_2O from the liver is possible. An inspection of the above data shows quite conclusively, at least so far as phosgene and chlorpicrin are concerned, that total solids are distinctly increased in the muscle during the development of edema, in other words, H_2O is lost from this tissue. In Figures 49 and 50 graphs for solids in muscle are presented. These curves indicate clearly that water does not enter the muscle during the period of the development of edema. In other words, edema is not general. On the other hand, they present evidence for the view that water is drawn *from* the muscles.

TABLE XLVIII

SOLIDS IN FRESH TISSUE

Phosgene Dogs

Dog No.	*Hours after gassing*	*Liver per cent*	*Muscle per cent*
1096	1	26.8	25.2
1005	1½	26.7	29.9
976	2	26.3	26.0
1100	2	25.2	25.4
1101	2	27.0	24.8
975	2½	25.6	32.6
974	3	23.5	25.6
1099	3	28.6	25.0
1110	3½	26.6	24.6
973	3½	25.5	24.1
972	4		28.2
1095	4	26.9	25.6
1102	4	29.4	44.5
1103	4	28.2	25.6
1109	4½	26.0	26.2
1041	5	27.6	36.5
1108	5	23.4	24.4
1097	5	27.3	25.6
1104	6	24.5	25.7
1098	6	25.7	25.1
1049	6	26.2	23.4
1107	6½	26.3	26.7
1040	7	25.9	37.1
1050	8	26.6	26.3
1051	10	26.8	25.0
981	12½	27.2	27.8
1037	13	25.6	23.0
1039	13	22.8	23.1
1038	14	24.9	22.8
980	14½	26.2	26.3
978	15½	26.8	22.4
979	16	30.1	27.7
1003	16	26.0	28.3
977	19	Lost	Lost
1044	21	27.0	24.2
1004	24	26.5	25.2
1061	28	29.2	24.3
998	3½ days	26.2	26.4
999	4½ days	27.7	22.7
994	5 days	25.3	23.9
970	Less than 9 hours	25.9	28.9
971	18?	27.3	25.6
1029	2½ days	26.6	23.2

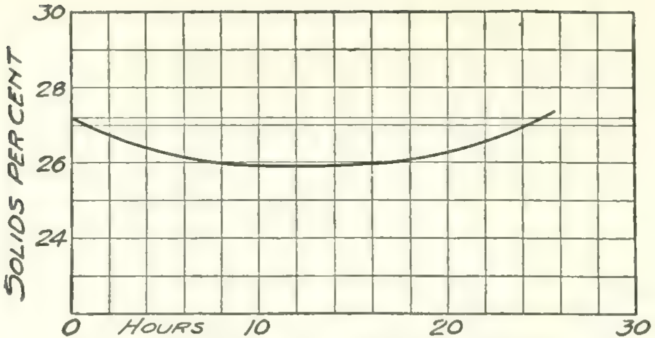

Fig. 47 Total Solids in Liver Tissues after Phosgene Poisoning.

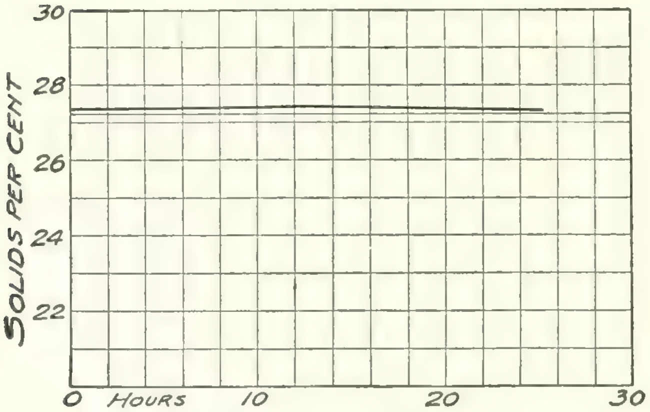

Fig. 48. Total Solids in Liver Tissue after Chlorpicrin Poisoning.

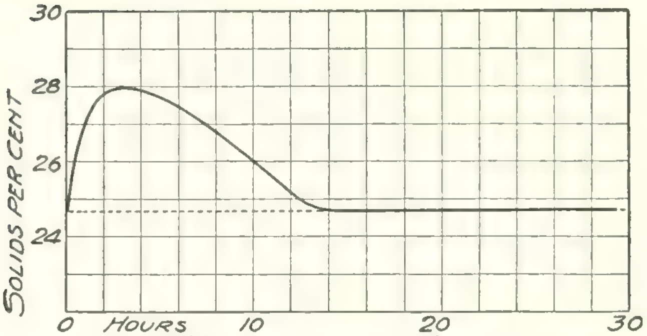

Fig. 49. Total Solids in Muscle Tissue after Phosgene Poisoning.

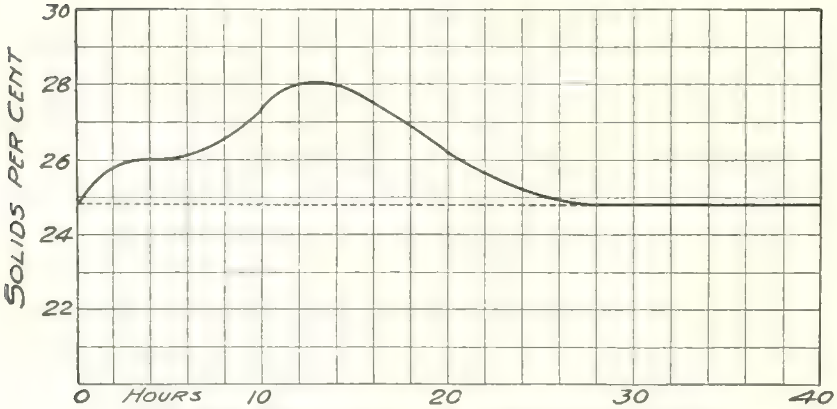

Fig. 50. Total Solids in Muscle Tissue after Chlorpicrin Poisoning

As a tentative hypothesis it may, therefore, be accepted that during the development of pulmonary edema fluid is drawn from the other tissues—perhaps specifically from muscle tissue.

F. *Edema and Permeability of Blood Vessels.*

A discussion of edema would be incomplete without reference to a possible change in the permeability of the blood vessels, either general or local, since in a theoretical consideration of the production of edema it is generally assumed that alterations in vascular permeability may be a significant factor.

In the experiments to be reported, dogs were infused with sodium chloride solutions before and after gassing and changes in blood volume were measured at short intervals after infusion. This method gives the rate of return to the normal of the augmented blood volume after infusion; in other words, the rate of disappearance of the infused fluid is determined and an indication is obtained of the comparative permeability of the blood vessels.*

Considerable careful work was first done to determine the applicability of the determination of hemoglobin to the measurement of blood volume. Samples taken from ear vessels are absolutely worthless unless a clean cut is made with the lancet, resulting in a copious flow of blood which appears without manipulation or rubbing. Into the jugular vein of normal dogs was infused physiological saline solution, at 38°, so that a volume equal to 1 per cent of the body weight was injected in approximately one minute. Samples were taken from the ear before infusion and at one minute intervals after infusion until the blood volume returned to that indicated by the hemoglobin before infusion. Two hundredths of a cubic centimeter of blood was measured by a Sahli pipette and delivered into 6 cubic centimeters of weak ammonia water. Coal gas was then passed through until the hemoglobin was changed to CO—hemoglobin, when the color was compared to a standard 1 per cent solution of CO—hemoglobin in an Autenrieth colorimeter.

With gassed dogs the procedure was the same with the exception that blood to the extent of 1 per cent of the body weight was withdrawn one hour after gassing as in the standard treatment.† The infusion was made five hours after gassing, when the blood usually had concentrated above normal. A comparison of the time for the blood volume to return to normal after infusion in the normal dog with the corresponding time in the gassed dog, gives an indication of comparative permeability.

The results obtained are definite (see Table XLIX). The time for the infusion fluid to disappear varied from 0 to 21 minutes in normal dogs and from 8 to 33 minutes in gassed dogs. In all dogs save one, the time for the infusion fluid to disappear was longer after gassing than in the normal dog. The time for infusion fluid to disappear in normal dogs varies, *i.e.*, it is an individual characteristic and the decrease in permeability after gassing likewise varies with different dogs. It should be emphsized that there is no evidence of increased permeability, with a single exception, and a very definite indication that the permeability of the vessels is somewhat decreased during the stage of phosgene poisoning studied.

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*See Bogert, Underhill and Mendel, Am. Journ. Physiol., 1916, xli, p. 189.

†This was done for a purpose having no connection with the present investigation and does not militate against the conclusions drawn, inasmuch as this procedure did not noticeably change the development of edema.

TABLE XLIX

Studies in Permeability

The Rate of Disappearance of Infused Fluid in Normal Dogs and in Dogs Gassed with Phosgene

Before Gassing			*After Gassing*		
Minutes after infusion	*Hemoglobin*		*Minutes after infusion*	*Hemoglobin*	
		Dog 889			
Normal	102		Before infusion	110	Gassed 86
1	89		1	92	
2	99	Infused 200 cc. in 1 min.	2½	92	Infused 200 cc. in 1 min. 10 sec.
2½	86		3	93	
3½	85		4	95	
4	89		5	95	
5½	86		8	99	
6½	87		9	102	
7	92		11	105	
10	107	Time for infusion to disappear 10 minutes	13	110	Time for infusion to disappear 13 minutes
13	99		15	108	
16	99		19	111	
		Dog 890			
Normal	90		Before infusion	97	Gassed 81
1	80	Infused 220 cc. in 1½ min.	½	85	Infused 200 cc. in 1 min. 10 sec.
2	82		1	86	
2½	79		1½	89	
6	84		3	92	
8	81		5	92	
9	84		7	92	
11½	86		9	95	
12	84		12½	93	
12½	92	Time for infusion to disappear 12½ minutes	14½	99	Time for infusion to disappear 14½ minutes
14	93		16½	98	
16	91				
		Dog 884			
Normal	89		Before infusion	129	Gassed 83
1	86		½	114	Infused 175 cc. in 1 min. 10 sec.
2	89	Infused 150 cc. in 1 min.	2	117	
3	89		3	120	
4	87		4	120	
5	92		5	125	
6	86		6	123	
8	89		7½	122	

TABLE XLIX (*Continued*)

		Before Gassing			*After Gassing*
Minutes after infusion	*Hemoglobin*		*Minutes after infusion*	*Hemoglobin*	
		Dog 884 (Continued)	Before infusion		
8½	89		9	123	
12	90		11½	129	Time for infusion to disappear 11½ minutes
16	90	Time for infusion to disappear—immediately			
19	89		13½	129	
20	89		16½	130	
		Dog 876			
Normal	123	Infused 100 cc. in 1 min. 10 sec.	Before infusion	123	Gassed 84
½	92		½	110	Infused 100 cc. in 1 min.
1	108		1	105	
2	108		1½	106	
3	102		2	108	
4	111		2½	105	
5	107		4	106	
6	105		5	112	
7	116		6	117	
8	117		10½	117	
11	114		13½	109	
15	117		20	117	
19	123	Time for infusion to disappear 19 minutes	33	123	Time for infusion to disappear 33 minutes
			41	122	
		Dog 877			
Normal	117		Before infusion	125	Gassed 84
1	102	Infused 125 cc. in 1½ min.	½	110	Infused 125 cc. in 1 min.
1½	99		1	108	
3	111		1½	111	
6	98		2	102	
7½	105		3	108	
16	99		4	104	
21	117	Time for infusion to disappear 21 minutes	8	116	
			8½	108	
22	117		9	111	
23½	120		11½	114	
			15½	110	
			18½	113	
			22	123	Time for infusion to disappear 22 minutes
			26	124	
			30½	125	
			31½	126	

TABLE XLIX (*Continued*)

Before Gassing			*After Gassing*		
Minutes after infusion	*Hemoglobin*		*Minutes after infusion*	*Hemoglobin*	
Normal	120	Dog 883	Before infusion	108	Gassed 86
½	111	Infused 200 cc. in 1 min.	¼	106	
1½	109		½	97	Infused 200 cc. in 1 min. 10 sec.
2	86		2	98	
3	108		2½	97	
3½	108		3½	102	
5	107		5	102	
6	108		8	108	Time for infusion to disappear 8 minutes
6½	92				
8	109				
10	114				
10½	99				
13	111				
16½	117 *				

* This dog presented an anomalous picture. This value was the closest to normal to which he came back.

Before Gassing			*After Gassing*		
Minutes after infusion	*Hemoglobin*		*Minutes after infusion*	*Hemoglobin*	
Normal	123	Dog 882	Before Infusion	138	Gassed 88
1	105	Infused 150 cc. in 1 min.	1½	117	Infused 150 cc. in 1 min.
1½	106		2	123	
2	106		2½	126	
2½	107		3½	122	
3	99		5	117	
5	114		6	120	
9	112		6½	126	
12	110		7	129	
16½	120	Time for infusion to disappear 16½ minutes	9½	127	
			10½	129	
18	120		12	129	
			14	130	
			16	130	
			18	132	
			19	131	
			21	135	
			24½	138	Time for infusion to disappear 24½ minutes
			26½	136	

From the foregoing considerations it may be accepted that the development of edema as a result of the action of the lethal war gases is associated with well-defined changes in the fluid and salt content of the blood and tissues without an apparent increase in the permeability of the blood vessels. Fluid and salt probably pass from the tissues to the blood in an attempt to compensate the latter for its loss in those constituents which mobilize in the lungs, resulting in edema. Later if edema subsides there may be reabsorption of fluid and salt, a portion being redistributed to the tissues, the remainder being excreted through the kidneys. Such a hypothesis is supported by the correlation existing between the production and subsidence of edema, and the excretion of chlorides through the urine previously discussed.*

*See Chapter V on Urine.

CHAPTER IX

OXYGEN CHANGES IN THE BLOOD

From the fact that the lethal war gases exert a specific action upon the respiratory mechanism leading to impairment of the mechanism of respiration it is obvious that distinct changes in the respiratory function of the blood are to be anticipated. This view is corroborated by the superficial observation that the blood changes in both its consistency and color. It becomes viscid and thick, and instead of possessing the normal bright red hue may assume a maroon color, often appearing almost black. The subject of the respiratory function of the blood is of extreme importance, since upon its proper performance depends adequate tissue nutrition and continued existence of the organism as a whole. Oxygen starvation is an exceedingly serious condition resulting in impairment of all bodily functions, and if sufficiently grave culminating in cessation of all vital activity.

1. *Oxygen Capacity of the Blood.**

By the oxygen capacity of blood is meant the cubic centimeters of oxygen in 100 cubic centimeters of blood which has been thoroughly aerated with atmospheric air at room temperature. Obviously the oxygen capacity of the blood is a measure of the hemoglobin present. From comparative studies of the total solids of the blood and oxygen capacity it appears that variations in oxygen capacity and hemoglobin can be accounted for by variations in the concentration of the blood by the lethal war gases.

With phosgene poisoning there are three distinct periods of fluctuation of the oxygen capacity (see Table L). First, in all but a few dogs there is a diminution of the oxygen capacity immediately after gassing which lasts from 4 to 7 hours. Secondly, there is an increase of the oxygen capacity which, in dogs that die, reaches a maximum between 8 and 12 hours, but in dogs that live this value reaches a maximum later. The third period marks a decrease in the oxygen capacity to normal which is reached at the 24th to 30th hour after gassing. The value for oxygen capacity may fall to a figure slightly below normal during this later period. The above picture is the usual one to which by far the largest number of animals conform. Occasionally, there is observed a case in which there is no diminution of oxygen capacity immediately after gassing, but instead a rapid increase to a maximum. These animals usually die. Occasionally also one sees an animal whose oxygen capacity does not change at all, but fluctuates about the normal, during the entire period of observation. These animals usually live. All of these oxygen capacity figures are paralleled by total solids figures so that is seems justifiable to assume that we are not dealing with newly intruded corpuscles, but only with changes in the concentration of the blood. The oxygen capacity was determined in both venous and arterial blood, the values being the same in both cases.

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*The methods of Haldane and Barcroft were employed in the determination of changes in the gases of the blood.

TABLE L

Oxygen Content and Capacity and the Percentage Saturation of Arterial and Venous Bloods in Animals Gassed with Phosgene

Dog No.	*Conc.*	*Hours After Gassing*	*O_2 Cap.*	*Art. Content*	*Ven. Content*	*Art. Sat.*	*Ven. Sat.*	*Result*
No. 324	79	0	25.8	24.0	20.6	93	86	
		½	22.4	17.8	12.0	80	55	
		5½	27.7	19.6	12.9	71	57	
		10½	30.1	19.4	6.7	64	22	Died
No. 337	77	0	24.7	23.4	17.9	95.3	76	
		2	23.0	20.8	16.4	91	71	
		20	31.0	26.7	11.3	86	36	
		24	29.7	24.0	12.0	81	40	
		35	26.5	23.5	14.6	89	55	
		45	23.8	21.5	11.2	90	47	Recovered
No. 383	77	0	22.1	22.6	16.0	100	71	
		½	21.2	20.9	14.6	99	69	
		4½	22.9	22.5	15.0	98	66	
		8½	23.4	20.8	11.9	89	51	
		24	23.0	15.6	6.7	68	29	
		28	23.5	12.9	4.9	55	21	Died
No. 386	78	0	19.0	19.0	14.2	98	73	
		2	16.3	16.3	7.0	100	43	Died
No. 395	79	0	22.7	21.0	18.7	93	83	
		2	20.4	20.0	16.6	98	81	
		6	24.1	21.8	16.5	90	69	
		23½	32.6	19.6	7.1	60	22	
		26½	32.7	18.7	5.0	57	15	Died
No. 426	79	0	22.0	21.9	13.0	99	59	
		16	25.6	19.2	6.6	75	26	
		19	25.5	11.2	3.6	44	14	
		22	24.6	——	2.2	—	9	Died
No. 434	78	0	25.2	24.8	21.4	99	85	
		1	20.4	16.4	10.6	80	52	
		5	21.0	18.3	11.3	87	59	
		10½	22.3	20.1	14.0	90	63	
		14	23.4	21.4	11.6	91	50	
		24	26.7	21.0	9.6	79	36	
		27	24.6	21.4	10.0	87	41	
		30	23.7	18.9	11.2	80	47	
		48	23.1	17.3	10.9	75	47	
		51	22.5	17.3	10.9	77	48	Recovered

TABLE L (*Continued*)

Dog No.	*Conc.*	*Hours after Gassing*	*O_2 Cap.*	*Art. Content*	*Ven. Content*	*Art. Sat.*	*Ven. Sat.*	*Result*
No. 406	114	0	23.3	22.5	17.1	96	73	
		1	20.5	19.7	10.1	96	49	
		4	22.3	19.3	12.1	87	54	
		7	25.8	22.1	12.9	86	50	
		10	33.4	21.4	5.8	64	17	
		23	32.0	16.8	5.0	52	16	Died
No. 710	94	0	27.4	25.7	16.4	94	60	
		1	23.2	21.8	17.2	94	74	
		5	23.4	22.5	17.4	96	74	
		8	25.0	24.1	14.5	96	58	
		13	27.2	—	12.8	—	51	
		17	29.2	26.6	—	91	—	
		22	29.2	—	—	—	—	Recovered
No. 486	69	0	20.4	20.9	16.9	100	83	
		1	18.8	16.5	12.6	88	67	
		4	21.2	18.1	14.2	85	67	
		9	24.3	18.2	5.6	75	23	
		13	24.9	13.9	4.6	56	18	Died
No. 496	63	0	25.3	23.8	17.3	94	68	
		2	22.7	21.8	14.3	63	63	
		6	23.9	21.2	16.3	89	68	
		9	26.6	24.0	16.4	90	62	
		13	29.3	25.3	10.7	86	36	
		24	31.4	21.6	14.4	69	46	
		30	26.6	20.9	11.3	79	42	
		36	25.3	17.7	14.2	70	56	
		48	23.2	16.9	11.6	71	50	
		72	24.4	14.9	14.1	61	58	Recovered
No. 624	65	0	24.3	23.1	16.4	95	67	
		½	22.6	21.9	15.5	97	69	
		3	24.1	20.7	14.4	86	60	
		7	24.7	21.8	16.9	88	68	
		10	27.0	24.8	16.0	92	59	Recovered
No. 669	53	0	23.6	21.9	17.0	93	72	
		1	20.9	18.3	14.3	87	68	
		5	21.2	20.4	13.3	96	63	
		9	22.9	20.7	11.9	91	52	
		13	28.2	21.6	11.9	77	42	
		17	29.8	22.3	13.4	75	45	
		21	28.6	19.3	14.3	68	50	
		25	28.6	19.4	11.5	68	40	

TABLE L (*Continued*)

Dog No.	*Conc.*	*Hours After Gassing*	*O_2 Cap.*	*Art. Content*	*Ven. Content*	*Art. Sat.*	*Ven. Sat.*	*Result*
No. 669		30	27.1	21.9	12.5	81	46	
(Continued)		38	23.9	—	14.1	—	59	
		47	24.7	20.3	14.4	72	58	
		73	20.0	17.4	—	87	—	Recovered
No. 683	54	0	17.2	16.8	9.8	95	55	
		3	19.4	16.3	9.7	84	50	
		7	21.1	18.0	8.6	85	41	
		11	20.6	19.0	8.1	92	39	
		15	22.4	18.0	5.9	80	26	
		23	22.6	16.1	5.2	71	23	
		28	23.5	16.9	7.1	72	30	
		34	21.6	17.3	5.0	80	23	
		48	22.2	15.6	—	70	—	Recovered
No. 684	53	0	25.1	24.7	18.1	98	72	
		3	28.3	25.7	—	91	—	
		7	30.3	29.1	15.0	96	50	
		11	31.1	28.2	10.0	91	32	
		15	36.7	—	6.8	—	19	Died
No. 698	58	0	19.5	19.5	13.7	100	70	
		1	16.4	15.6	10.2	95	62	
		5	20.4	17.3	6.2	85	30	
		9	27.5	14.7	4.9	53	18	Died
No. 665	45	0	25.0	22.5	18.4	90	74	
		1	24.5	19.3	13.4	79	55	
		5	25.0	20.6	15.2	82	61	
		9	23.5	—	10.7	—	46	
		13	24.0	21.0	11.6	88	48	
		17	26.7	22.8	10.7	85	40	
		21	26.3	22.9	11.2	87	43	
		26	24.4	—	6.3	—	34	
		37	25.5	20.7	7.6	81	30	
		48	24.9	18.2	6.4	73	26	
		72	20.7	—	9.9	—	48	Recovered
No. 699	49	0	25.7	23.1	15.1	90	59	
		1	22.2	20.4	12.9	92	58	
		5	26.6	23.2	12.5	87	47	
		9	28.4	27.1	17.4	95	61	
		13	27.6	27.2	11.6	99	42	
		17	29.2	25.3	16.1	87	55	
		21	31.6	26.2	12.6	83	40	
		27	32.6	30.4	20.4	93	62	

TABLE L (*Continued*)

Dog No.	*Conc.*	*Hours After Gassing*	O_2 *Cap*	*Art. Content*	*Ven. Content*	*Art. Sat.*	*Ven. Sat.*	*Result*
No. 699		35	27.9	24.8	——	89	—	
(Continued)		48	25.0	24.2	——	97	—	Recovered
No. 723	45	0	20.9	18.8	——	90	—	
		3	20.2	18.5	——	95	—	
		7	26.4	20.7	——	78	—	
		11	27.5	19.2	——	70	—	
		15	27.5	2.6	——	9	—	Blood from left ventricle after death
No. 724	43	0	24.0	24.1	——	100	—	
		4	22.4	20.7	——	93	—	
		7	25.5	22.0	——	87	—	
		11	28.9	26.3	——	91	—	
		15	29.5	16.5	——	55	—	Venous?
		19	30.5	19.4	——	64	—	
		23	27.6	17.0	——	62	—	
		30	12.2	1.3	——	9	—	Blood from ventricle after death
No. 725	38	0	29.0	25.6	——	88	—	
		2½	22.0	21.9	——	99	—	
		7	21.7	20.9	——	96	—	
		11	24.5	24.1	——	99	—	
		15	26.3	23.3	——	88	—	
		19	23.1	22.4	——	97	—	
		27	25.0	22.4	——	90	—	
		32	24.7	22.1	——	90	—	
		59	23.8	21.5	——	91	—	Recovered
No. 726	38	0	28.2	24.8	——	86	—	
		3	23.3	22.4	——	96	—	
		7	23.1	19.2	——	82	—	
		11	25.3	23.4	——	93	—	
		15	25.4	23.8	——	94	—	
		19	28.2	24.3	——	86	—	
		23	26.7	25.1	——	94	—	
		32	23.4	23.0	——	98	—	
		68	22.8	21.6	——	95	—	Recovered

TABLE LI

Oxygen Content and Capacity and the Percentage Saturation of Arterial and Venous Bloods in Animals Gassed with Chlorpicrin

Dog No.	*Conc.*	*Hours After Gassing*	O_2 *Cap.*	*Art. Content*	*Ven. Content*	*Art. Sat.*	*Ven. Sat.*	*Result*
No. 254	81	0	25.8	25.0	18.0	97	70	
		1	26.3	23.7	9.3	90	35	
		4	29.0	26.8	11.5	92	40	
		9	30.4	26.5	11.2	87	37	
		12	30.7	29.5	8.5	96	28	
		16	29.9	27.3	8.0	91	27	
		20	26.6	25.5	11.8	96	44	
		24	25.5	25.0	14.3	98	56	
		28	25.9	23.7	13.4	92	52	
		35	26.6	26.2	12.6	98	47	
		37	24.4	23.1	11.6	95	48	
		41	25.1	22.8	9.6	91	38	Recovered
No. 258	83	0	29.4	28.2	24.3	96	83	
		1	29.4	27.7	14.2	94	48	
		4	30.2	28.0	17.3	93	57	
		8	30.5	28.7	15.2	94	50	
		12	30.6	29.3	9.5	96	31	
		16	30.0	28.9	14.0	96	47	
		21	30.0	27.8	13.6	93	45	
		27	29.9	25.5	13.6	85	46	
		30	29.1	24.1	12.7	83	44	
		36	29.5	25.6	11.7	87	40	
		46	24.0	21.4	11.8	89	59	Recovered
No. 264	70.3	0	26.9	24.6	23.3	91	87	
		1	26.7	24.5	16.4	92	61	
		4	30.2	27.9	16.7	92	55	
		9	31.8	26.9	15.3	85	48	
		13	32.7	——	14.4	—	44	
		15	32.9	28.0	11.2	85	34	
		21	31.2	28.2	11.4	90	37	
		29	25.4	25.0	8.0	98	32	
		38	26.0	25.6	——	98	—	Recovered
No. 297	129	0	26.7	22.6	12.9	85	48	
		½	26.4	20.3	9.7	77	37	
		2	27.3	24.7	10.1	91	37	
		4	27.3	——	12.8	—	47	Died
No. 303	75	0	24.2	20.8	19.0	86	79	
		1	22.2	20.1	12.1	90	54	
		2	26.6	21.5	11.2	81	42	

TABLE LI (*Continued*)

Dog No.	*Conc.*	*Hours After Gassing*	*O^2 Cap.*	*Art. Content*	*Ven. Content*	*Art. Sat.*	*Ven. Sat.*	*Result*
No. 303 (Continued)		4	23.9	22.3	13.4	93	56	
		7	24.8	25.3	14.7	100	59	
		24	25.4	23.5	16.8	93	66	Recovered
No. 304	82	0	35.4	34.4	31.2	97	88	
		½	34.4	31.3	——	91	—	
		3	34.2	24.0	9.3	70	27	
		5	34.4	22.7	8.0	66	23	
		22	32.0	28.1	10.0	88	31	Recovered
No. 310	71	0	25.2	21.1	16.0	84	64	
		1	25.0	21.1	12.4	84	49	
		2	25.8	21.9	12.3	85	48	
		4	27.8	23.9	10.8	86	39	
		5	26.4	22.9	10.3	87	39	
		6	26.7	20.5	9.4	77	35	
		7	24.2	21.4	10.7	88	44	Recovered
No. 314	79	0	30.8	28.2	22.7	92	74	
		½	30.2	25.3	12.7	84	42	
		2	30.5	25.2	13.5	83	44	
		4	27.8	23.9	13.9	86	50	
		5	28.3	25.2	12.2	89	43	
		7	29.0	26.1	9.4	90	32	
		24	28.7	27.4	12.5	95	44	Recovered
No. 323	75	0	28.3	25.5	21.8	90	77	
		1	28.2	25.7	12.9	91	46	
		3	29.3	26.2	17.2	89	59	
		6	28.8	26.2	14.9	91	52	
		8	31.6	27.6	15.4	87	49	
		10	32.0	27.1	14.9	85	47	
		13	31.7	27.0	16.0	85	46	
		31	28.4	26.2	18.5	92	65	
		60	27.4	24.1	16.5	88	60	Recovered
No. 329	73	0	25.5	24.0	15.7	94	62	
		1	24.5	22.8	11.9	93	49	
		3	27.6	9.5	4.1	34	15	Died
No. 335	86	0	24.3	22.3	15.9	92	65	
		½	22.1	20.0	13.2	91	62	
		3	24.5	20.1	11.2	82	46	
		5	25.0	19.7	9.9	79	40	
		7	24.3	19.3	10.3	79	42	
		11	23.6	18.6	9.8	79	42	
		24	22.1	17.8	9.2	81	42	Recovered

TABLE LI (*Continued*)

Dog No.	*Conc.*	*Hours After Gassing*	*O_2 Cap.*	*Art. Content*	*Ven. Content*	*Art. Sat.*	*Ven. Sat.*	*Result*
No. 339	86	0	27.9	23.3	16.5	83	59	
		½	25.4	22.2	5.8	87	23	
		8	35.0	20.3	7.0	58	20	
		12	32.0	21.1	7.9	65	24	Died
No. 343	70	0	26.5	25.0	21.1	94	80	
		½	25.4	25.1	9.0	99	35	
		13	32.0	29.4	17.8	92	56	
		16	30.9	27.9	15.9	90	51	
		20	29.5	26.1	12.4	89	42	
		25	28.9	26.7	10.9	92	28	
		31	26.4	24.9	17.2	94	65	
		40	29.7	27.1	17.8	91	60	
		47	28.8	25.2	12.6	88	44	Recovered
No. 346	77	0	24.9	21.9	14.0	88	56	
		½	23.0	22.8	6.7	99	29	
		9	29.8	23.8	8.1	80	27	
		13	32.0	28.3	5.3	88	17	Died
No. 348	74	0	28.3	22.1	16.8	78	59	
		½	25.4	24.5	14.9	97	59	
		12	32.0	28.5	16.0	89	50	
		16	33.0	28.9	17.8	88	54	
		20	32.3	29.5	8.9	91	28	
		24	25.8	24.1	10.8	93	42	
		31	24.8	24.6	9.1	99	37	
		40	26.6	24.9	10.0	94	38	
		48	27.2	25.6	10.5	94	39	Recovered
No. 351	77	0	27.1	24.8	19.0	92	70	
		½	24.0	20.0	9.1	83	38	
		13	30.6	22.3	19.6	73	64	
		17	29.4	26.3	18.1	90	62	
		21	27.7	26.1	17.1	95	62	
		25	28.7	24.0	14.5	84	51	
		34	28.4	25.4	16.8	89	59	
		40	27.2	24.2	16.4	89	60	
		49	27.4	27.0	18.3	99	52	Recovered
No. 355	78	0	27.0	25.8	19.1	96	71	
		½	28.0	19.6	8.0	70	29	
		12	31.1	23.1	8.2	74	26	
		16	32.5	23.6	7.3	73	22	
		20	28.8	23.3	5.0	81	17	
		24	28.4	25.4	10.5	89	37	

TABLE LI (*Continued*)

Dog No.	*Conc.*	*Hours After Gassing*	*O_2 Cap.*	*Art. Content*	*Ven. Content*	*Art. Sat.*	*Ven. Sat.*	*Result*
No. 355		32	26.7	25.9	16.4	97	61	
(Continued)		40	27.5	26.4	17.3	96	63	
		48	25.6	21.5	12.3	84	48	Recovered
No. 358	83	0	25.7	24.3	11.3	95	44	
		½	24.9	24.9	6.4	100	26	
		12	29.8	27.2	12.2	91	41	
		16	31.3	28.3	11.0	90	35	
		20	25.8	18.7	12.8	73	50	
		28	25.6	25.3	11.3	99	44	
		32	27.1	13.6	5.5	50	20	Died
No. 361	111	0	30.3	28.1	14.9	93	49	
		½	28.7	26.8	10.0	93	35	
		10	28.4	24.5	13.6	86	48	
		13	30.3	28.6	13.6	94	45	
		17	32.9	31.8	12.7	97	39	
		21	30.0	28.1	9.1	94	30	Died
No. 364	116	0	27.5	26.2	9.2	95	33	
		½	28.4	26.3	23.2	93	82	
		6	28.4	25.4	13.9	90	49	
		12	31.1	29.1	18.2	94	59	
		16	26.8	23.6	10.4	88	39	
		20	26.6	21.8	11.4	82	43	
		24	28.5	26.3	16.3	92	59	Recovered
No. 367	100	0	28.9	27.8	19.6	96	68	
		½	26.1	26.1	7.8	100	30	
		9	32.4	30.4	8.2	94	26	
		12	33.3	30.9	7.7	93	23	
		16	33.1	29.1	8.6	91	26	
		19	31.0	25.3	12.0	76	39	
		24	31.2	18.3	6.4	59	21	
		31	30.4	20.6	11.4	68	37	
		37	30.9	23.4	13.7	76	44	
		43	31.2	24.7	13.7	80	44	Died
No. 369	105	0	28.4	28.1	19.6	99	70	
		½	26.9	23.0	19.3	85	71	
		3	30.2	27.3	7.8	82	25	Died
No. 372	108	0	29.6	28.1	23.2	95	79	
		½	28.2	27.4	9.6	97	34	
		5	30.5	15.1	14.2	50	47	
		9	32.2	14.6	9.1	45	28	Died

TABLE LI (*Continued*)

Dog No.	*Conc.*	*Hours After Gassing*	*O_2 Cap.*	*Art. Content*	*Ven. Content*	*Art. Sat.*	*Ven. Sat.*	*Result*
No. 373	139	0	21.5	20.0	15.0	93	70	
		½	23.8	19.9	9.0	83	38	
		4	25.9	22.0	8.3	85	32	
		8	30.4	9.6	5.5	32	18	Died
No. 377	157	0	25.3	23.3	13.7	92	45	
		½	23.0	20.9	10.0	91	44	
		2	24.7	18.8	6.3	76	25	
		3	26.3	20.2	5.8	77	22	
		6	27.7	22.0	10.3	80	37	
		9	29.0	23.7	10.8	82	37	Recovered
No. 378	138	0	21.5	20.1	11.9	94	55	
		½	21.8	18.7	4.5	86	23	
		2	24.9	21.5	5.4	86	22	
		6	28.0	23.3	6.7	83	24	
		10	27.2	22.9	8.5	84	31	Recovered
No. 390	79	0	30.6	24.4	20.7	80	68	
		½	26.3	24.8	9.9	94	38	
		9	34.8	27.5	9.2	79	26	
		12	36.8	28.9	8.3	79	23	
		16	41.0	29.8	8.7	73	21	
		20	43.4	28.4	7.3	65	17	Died
No. 392	124	0	27.8	25.4	23.1	91	83	
		½	27.4	24.5	7.9	90	29	
		4	31.9	30.4	10.6	95	23	
		6	34.2	28.9	7.8	85	24	
		9	33.7	27.9	8.7	83	25	Died
No. 396	140	0	24.7	23.3	10.1	93	41	
		½	25.4	22.6	12.7	99	54	
		2	27.1	26.3	9.1	97	33	
		5	27.4	27.1	9.5	99	35	
		7	29.1	27.4	7.6	93	26	
		9	30.0	27.4	8.1	92	27	
		12	29.6	27.9	7.2	94	24	Died

The picture with reference to oxygen capacity then is as follows: an immediate decrease, a subsequent increase to a maximum, followed by a return to normal or subnormal. These changes are independent of the concentration of gas to which the animal was exposed.

Immediately (up to 1 hour) after gassing with chlorpicrin the oxygen capacity fell down markedly in 17 animals, slightly in 5, did not change in 2, rose slightly in 2, and markedly in 3. Treated statistically, this evidence indicates that there is a dilution of the blood in a majority of animals immediately after gassing with chlorpicrin (see Table LI).

TABLE LII

Comparison of Oxygen Capacity of Venous Blood before and after Chlorine Poisoning

Dog No.	*Gas Conc.* *mgm. per liter*	*Hours after gassing*	Oxygen Capacity	
			Volumes per cent O_2	*Increase per cent of normal*
4	0	0 (Normal)	19.5	
	2.85	1½	24.5	25.6
		24	21.4	9.7
		48	20.3	4.1
6	0	0 (Normal)	19.2	
	4.15	2	24.5	27.6
8	0	0 (Normal)	15.5	
	3.82	2	15.6	0.64
		4	18.0	16.1
		6	20.7	33.6
9	0	0 (Normal)	15.7	
	4.53	½	15.8	0.64
		2	17.3	10.2
		4	21.0	33.7
		6	22.4	42.6
12	0	0 (Normal)	18.8	
	3.68	2	20.4	8.5
		4	24.2	28.7
		6	26.1	38.8
		24	21.4	13.8
393	0	0 (Normal)	17.4	
	2.57	1	22.7	30.5
		5	22.8	31.0
		22	24.7	42.0
394	0	0 (Normal)	18.2	
	2.48	½	29.5	62.1
		4	26.8	36.2
		23	31.1	71.0

This first period of lowered oxygen capacity is brief (much shorter than the corresponding period in phosgene poisoning) and lasts less than 2 or 3 hours. Occasionally, this lowered oxygen capacity persists in an animal for more than 24 hours. Two such animals in these experiments survived low concentrations of gas.

It is noteworthy that 12 of the 13 animals that died showed lowered oxygen capacity immediately after gassing. At low concentrations about one-half of the animals that showed this marked drop in oxygen capacity succumbed to gas poisoning. Of the 8 deaths at high concentrations, 7 showed diminished oxygen capacity immediately after gassing.

Following the initial short period of diminished oxygen capacity there comes a quick rise above the normal figure. This reaches its maximum between the 12th and 16th hours in animals that survive. The maximum may come as early as the 4th hour, and as late as the 24th. In dogs that died, the maximum usually was found at the time of death. At high concentrations of gassing this maximum seemed to come rather early (4 to 10 hours).

Finally, there is a third period in surviving animals when the oxygen capacity drops to the normal or slightly below normal in 24 to 48 hours.

Briefly, then, the picture with reference to oxygen capacity is as follows:

1, an immediate decrease lasting only an hour or two,

2, a subsequent increase to maximum at death or 12 to 16 hours,

3, a slow decrease to normal or subnormal.

A study of the blood of dogs gassed with chlorine demonstrated that after gassing there is always a significant rise in the oxygen capacity (see Table LII).

II. *Oxygen Content of Arterial Blood.*

By oxygen content is meant the cubic centimeters of oxygen in 100 cubic centimeters of blood just as it is drawn from the animal. The blood is drawn under oil to prevent contact with air, and in all the manipulation incident to the analysis contact with air is carefully avoided.

In the first period after gassing with phosgene in all dogs the oxygen content in arterial blood drops slightly (see Table L). In the second period the oxygen content tends to rise somewhat above normal in dogs that live, while in dogs that die it rises slightly then decreases steadily until death, when the value may be only half that of normal blood. In the third period in dogs that live the oxygen content falls back to normal or slightly below.

The oxygen content may also be expressed in percentage of the capacity which value is known as the *percentage saturation.* Expressed as such the percentage saturation in the first period is within normal limits. In the second period the percentage saturation may be within normal limits at first, but toward the last of this period and during the third period the percentage saturation falls to a point slightly below normal in dogs that live. In dogs that die the percentage saturation begins to fall during the second period and at death may be only half of the normal.

To summarize, the oxygen content of arterial blood taken as such does not vary greatly after gassing in dogs that live. When taken together with the increase in oxygen capacity, however, we can see that the percentage saturation of arterial blood falls after gassing.

In the first period after gassing with chlorpicrin (see Table LI) the oxygen content of the blood dropped somewhat in 19 dogs. It rose above normal in 6 dogs, and did not change in 4. This drop occurred in 90 per cent of the dogs gassed at high concentrations; while at low concentrations, only 60 per cent showed this initial drop. In animals that died, the arterial content of oxygen usually dropped as death approached.

In the second period (*i.e.*, after 3 or 4 hours from gassing), the arterial oxygen content tends to rise to a maximum which may appear sometime between 8 and 24 hours.

In the final period, the arterial oxygen content diminished, often to subnormal values.

In the period immediately after gassing, the percentage saturation of oxygen was within normal limits. It rose or fell in a manner somewhat parallel to the oxygen content discussed above. In 12 animals, the percentage saturation rose above the normal.

In the period following, the percentage saturation of the arterial blood usually dropped steadily for animals that died. In animals that survived, the percentage saturation did not go below 70. The lowest figure was reached usually between 12 and 18 hours. After that, it rose again to normal in 24 to 48 hours.

To summarize, the oxygen content of arterial blood taken as such does not vary enough in surviving gassed dogs to be appreciably significant. In dogs that succumb, the lowered arterial oxygen content is closely paralleled by the growing weakness of the animal.

The arterial oxygen saturation is actually increased immediately after gassing in a number of animals (12 out of 29) — mostly in those that die. No determinations were made with chlorine relative to the oxygen content of arterial blood.

III. *The Oxygen Content of Venous Blood.*

In dogs that live the value for oxygen content of venous blood after phosgene gassing drops slightly immediately after gassing and thereafter fluctuates about a value which is below normal (see Table L). In dogs that die, however, after the first decrease the value continues to drop rapidly until death, where the value for oxygen content in venous blood may be reduced to almost zero. Expressed as the percentage saturation, the value for venous blood is within normal limits during the first period, but drops to a lower level in periods two and three in dogs that live, while in dogs that die the percentage saturation falls during the second period to a value that sometimes is only one-fourth the normal.

TABLE LIII

OXYGEN CONTENT OF THE VENOUS BLOOD AFTER CHLORINE POISONING

Dog No.	*Gas Conc. mgm. per liter*	*Hours after Exposure*	*O_2 Content*
4	0	0 (Normal)	8.6
	2.85	2	7.2
		24	6.1
		48	4.4
		72	6.7
12	0	0 (Normal)	12.1
	3.68	0.5	6.2
		2.5	6.3
		4.5	4.6
		24	6.5
9	0	0 (Normal)	15.5
	4.64	0.5	8.2
		3.0	10.6
		5	4.6

The oxygen content of the venous blood after chlorpicrin gassing dropped immediately after gassing in nearly all animals (see Table LI). In those that lived, the drop was on an average the same as in those that died. This average value was between 50 and 60 per cent of the normal, regardless of the concentration of gas used.

In the great majority of surviving animals, the venous oxygen content *does not* return to normal in 48 hours. On the contrary, the value, though steadily increasing after the initial heavy drop due to gassing, remains usually at a low level for at least 48 hours.

The *percentage saturation* of the venous blood presents essentially the same picture as described above for the venous oxygen content.

In a general way, then, the blood oxygen picture in chlorpicrin poisoning is roughly similar to that found after phosgene gassing. If it is assumed that a drop in oxygen capacity is due to blood dilution and *vice versa*, we find that a majority (22 out of 29) of the animals studied here showed blood dilution immediately after gassing with chlorpicrin. The main difference in the initial dilution phases in phosgene and chlorpicrin poisoning is in the duration of dilution. With chlorpicrin it may last two or three hours, while with phosgene it is about six to eight hours long. Then follows the concentration of blood in both types of poisoning.

With chlorine gassing the oxygen content of venous blood usually shows a marked decrease which may be maintained for many hours (see Table LIII).

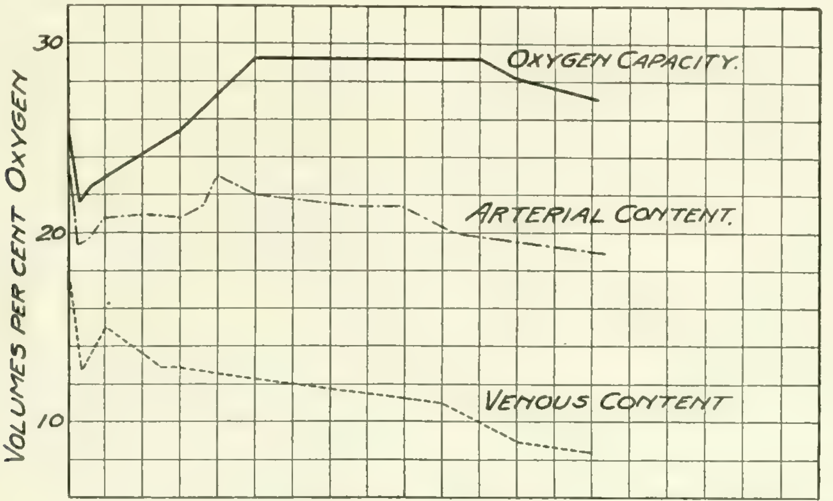

Fig. 51. Composite Curves of Oxygen Studies on Dogs Gassed with Phosgene (77–115)

Discussion of all Oxygen Data.

From the data presented it is quite apparent that the changes in arterial blood must be intimately associated with alterations in blood concentration. In all three instances the change in oxygen capacity and arterial content closely approximate the corresponding fluctuations in blood concentration. With phosgene and chlorpicrin the general character of changes under discussion is of the same kind, the difference being in the time relationships. The chlorine data differ in character from those of phosgene and chlorpicrin in that with chlorine there is no initial drop in the oxygen capacity or arterial content. Instead there is an immediate progressive rise. A graph representing the general changes in phosgene is shown in Figure 51. The corresponding chlorpicrin curve is so similar that it is omitted.

From the foregoing it may be concluded that changes in blood concentration adequately account for the observed alterations in oxygen capacity and arterial oxygen content. With phosgene and chlorpicrin there is a corresponding initial fall synchronous with the dilution of the first period and a marked rise coincident with the increase in blood concentration. The rise in oxygen capacity and oxygen in arterial blood with chlorine corresponds with the changes in blood concentration.

When oxygen in the venous blood is considered the changes observed with the three gases do not yield so simply to interpretation. It is true that the initial drop and first rise in oxygen content correspond with changes in blood concentration (see Figure 51, for phosgene). The long continued and progressive fall is undoubtedly associated with the rise in blood concentration. The mechanism whereby this is brought about may involve several factors. Some of the factors which need consideration are edematous fluid in the lungs, circulation rate, concentration of the blood. It has been asserted that in the presence of lung edema a film of water forms over the pulmonary capillaries, through which oxygen must pass in addition to the capillary wall. This would result in the blood in the pulmonary veins being deficient in oxygen. The arterial blood, then, with an abnormally high value of oxygen capacity does not have a corresponding high value for oxygen content, with the result that the percentage saturation drops in the arterial blood after the lung edema becomes well developed, that is, in the second period and the first part of the third period. Other conditions remaining constant such a state would result in the tissues being supplied with oxygen by blood subnormally saturated with oxygen and could lead to a drop in the content of venous oxygen.

This explanation, however, will not adequately account for the gradual *continued* fall in venous oxygen nor do other conditions remain constant. The blood continues to concentrate to a point where its passage through capillaries must become greatly impeded by the increased viscosity of the circulating fluid. In other words, the blood remains longer than usual in contact with the tissues and hence is robbed of an unusual quantity of oxygen. The continued increase in concentration ultimately reacts further upon the heart efficiency, less blood than usual being circulated in a given period, and even though the oxygen content of this blood may be abnormally high there is finally an insufficient oxygen supply carried to the tissues. In other words, the concentration of the blood causes a circulatory failure which becomes progressively worse as blood concentration increases and the oxygen of venous blood becomes progressively low. Under these conditions the tissues must suffer from lack of oxygen and the nervous mechanisms tend to assume a condition of narcosis.

The effect of oxygen want upon the heart will be to destroy its efficiency, the concentration and contracting force are decreased, and the heart may pass into a state of dilatation. As an accompaniment to the changes outlined above, the blood pressure may fall markedly and the animal pass into a condition greatly resembling shock.

The final analysis of the changes of oxygen in the blood leads back to the alterations of blood concentration as the primary cause.

CHAPTER X

ACIDOSIS

THE CONDITION resembling shock exhibited by animals after chlorine poisoning led to the study of acidosis. This was taken up by investigating the urine, the bicarbonate content of the blood and the hydrogen ion concentration of the blood. The nature of the carbon dioxide—bicarbonate equilibrium in the plasma makes the sodium bicarbonate assume the rôle of a respiratory compound. Alkali or rather sodium ions are constantly being drawn from the tissue reservoirs to hold carbon dioxide in the blood and also constantly pass into the tissue reservoirs when the carbon dioxide tension in the blood is less. In other words, there is a considerable "alkaline reserve" in the animal body. An abnormal appearance of acid in the body leads to a reduction of this reserve. Hence the measurement of this sodium bicarbonate concentration in the blood gives an index to the reaction of the body, *i.e.*, to the maintenance of the proper alkalinity or of an acidosis.

The method of Van Slyke and Cullen was used. The blood was drawn without loss of CO_2. The equilibrium $\frac{CO_2}{NaHCO_3}$ was established at room temperature and at the tension of CO_2 in alveolar air.

The results with gassed dogs lead to the conclusion that all animals gassed with chlorine show an immediate acidosis (lowered alkali reserve) of more or less severity (Table LIV). This lowering of the bicarbonate content of the blood is an invariable result of gassing and though the degree of this acidosis is extremely variable, it bears no relationship to the concentration of chlorine to which the animal was exposed (cf. Table LV, page 123). Some interesting correlations between the ability of the animal to withstand the acute stage of chlorine poisoning and the bicarbonate value were observed. *When the value falls from the normal, which ranges from 50 to 70, to below 40, the animal usually does not survive. Not all animals whose bicarbonate value rises after the first drop recover;* BUT ALL ANIMALS WHICH SURVIVE THE ACUTE PERIOD HAVE BICARBONATE VALUES RISING SHARPLY AFTER THE FIRST DROP (Table LVI, page 124). *Again, in animals which are gassed more than once there seems to be an overcompensation for the loss of alkali for each time the normal is higher than that before the previous gassing* (Table LVII, page 125). This same sudden drop in the bicarbonate value is also observed when the concentration of the gas is very low. This loss of bicarbonate can be made good to the animal by intravenous injection or per os administration of sodium bicarbonate (Table LVIII, page 126).

The causes of this acidosis are at best obscure. There are two theories, each of which has its good points. There are certain facts which point to the absorption of chlorine as the cause for the acidosis. The fact that there is an immediate lowering of the bicarbonate value points to a cause which operates immediately and is not cumulative This appears to be entirely independent of the concentration of the gas to which the animal is exposed. It has been demonstrated (page 26) that direct chlorine absorption probably does not

TABLE LIV

Carbon Dioxide Capacity of Blood after Chlorine Gassing

Dog No.	*Gas Conc. mgm. per liter*	*Hours after Exposure*	*CO_2 Capacity*
453	0	0 (Normal)	51.0
	2.50	Immediately	40.6
		2	50.2
		3	45.5
		4	34.8
434	0	0 (Normal)	56.7
	2.72	Immediately	42.5
		1	51.9
		2	57.8
		8	53.2
		23	52.2
440	0	0 (Normal)	54.1
	2.59	Immediately	42.8
		1	51.3
		3	50.4
		11	42.6
		23	43.5
441	0	0 (Normal)	47.5
	2.61	Immediately	42.6
		1	46.6
		3	47.5
		24	42.6
		48	46.4
449	0	0 (Normal)	51.9
	2.66	Immediately	36.5
		1	46.2
		3	51.9
		4	53.8
		5	52.8
		12	56.7
		23	51.0

account for the observed changes in the tissues and blood. On the other hand, in the experiments on the bicarbonate value of the blood the amount of chlorine calculated to be necessary to produce the observed acidosis is exceedingly small—too small in fact, to determine by our most refined methods of analysis. Again, in the urine we sometimes observe an immediate, though not large, increase in hydrogen ion concentration and usually in titratable acidity (page 22). These facts lead one to postulate a cause which is instantaneous in its action. The objection to the theory that the acidosis is due to the absorption of chlorine, is the absolute lack of all correlation between the concentration of chlorine in the mixture breathed by the dog and the degree of acidosis produced. Since it has been demonstrated that the musculature of the bronchioles contracts when the chlorine comes in contact with it, this may account for the inability of the chlorine to penetrate into the alveoli and hence for the independence of the chlorine concentration and the loss of alkali.

TABLE LV

Comparison of the Initial Drop in Carbon Dioxide Capacity with the Gassing Concentration

Dog No.	*Gas Conc. mgm. per liter*	*CO_2 Capacity Per cent of Normal*
32	2.41	14.1
31	2.71	10.9
29	2.86	37.2
30	3.00	11.3
22	3.35	3.5
24	3.38	6.3
18	3.37	40.6
20	3.62	24.9
8	3.82	13.4
16	3.86	34.8
6	4.15	7.9
9	4.53	20.0

The second theory is that of a carbon dioxide acidosis. When the chlorine strikes the lung tissue more or less irritation with the accompanying edema results. This edema and the excessive secretion of mucus along the nasopharyngeal passages and trachea are always well developed at the end of the half hour gassing period. Along with this edema, as a result of the chlorine irritation, appears the contraction of the muscles of the bronchioles. With the air passages contracted and the alveoli filling with edema fluid, the lung is rapidly becoming seriously impaired for the purpose of allowing a free passage of oxygen into, and of carbon dioxide out of, the blood stream. This accumulation of the CO_2 in the blood as the result of the inability of the CO_2 to leave the blood in the lung, if followed to its conclusion would merely result in a readjustment of the ratio $\frac{CO_2}{NaHCO_3}$ by calling forth more alkali from the tissue reservoirs. This is exactly what happens after some five or six hours in dogs which have a fund of alkali to draw upon. In the meantime, however, we have a rapidly increasing tension of CO_2 in the blood without a compensating increase in alkali

TABLE LVI

Carbon Dioxide Capacity of Blood in Dogs that Survive

Dog No.	*Gas Conc. mgm. per liter*	*Hours after Exposure*	*CO_2 Capacity*
12	0	0 (Normal)	54.0
	3.68	½	54.1
		2	59.8
		4	58.9
		6	58.9
		24	57.9
		96	62.6
18	0	0 (Normal)	55.9
	3.37	¼	33.2
		2	50.3
		4	59.8
		11	59.5
		22	61.5
79	0	(0 Normal)	53.0
	2.88	2	50.0
		6	51.9
		24	50.2
		29	53.8
		48	56.9
78	0	0 (Normal)	55.7
	2.64	2½	58.8
		6½	60.5
		26	55.7
		48	60.5
86	0	0 (Normal)	52.0
	2.77	2	56.9
		7	55.1
		24	53.0
		48	53.8
		101	61.6
41	0	0 (Normal)	52.8
	2.10	2	51.9
		5½	56.7
		53½	60.6

TABLE LVII

The Carbon Dioxide Capacity of the Blood of Dogs which have Recovered from Chlorine Poisoning

Dog No.	*Gas Conc. mgm. per liter*	*Hours after Exposure*	*CO_2 Capacity*	*Dog No.*	*Gas Conc. mgm. per liter*	*Hours after Exposure*	*CO_2 Capacity*
$3^{(1)}$	0	1st Normal	51.0	$5^{(1)}$ *	0	1st Normal	41.6
	2.16	2	42.5		1.95	24	47.3
		24	47.8			48	50.3
		48	42.2			72	51.2
		72	50.4				
				$5^{(3)}$	0	3rd Normal	59.5
$3^{(2)}$	0	2nd Normal	50.4		3.89	1	46.3
	3.01	2	46.5			6	59.5
		22	50.0			25	54.8
$12^{(1)}$	0	1st Normal	54.1	$18^{(1)}$	0	1st Normal	55.9
	3.68	1	54.1		3.37	¼	33.2
		3	59.8			3	50.3
		5	58.9			5	59.8
		24	57.9			12	59.5
						23	61.5
$12^{(2)}$	0	2nd Normal	55.7			30	59.4
	4.16	1	52.9			48	63.2
		6	53.8				
		25	53.8	$18^{(2)}$	0	2nd Normal	62.3
		49	56.7		3.86	1	50.7
						3½	51.6
$12^{(3)}$	0	3rd Normal	62.3			6½	50.7
	3.76	1	44.9				
		4½	54.5				
		24	57.5				

* Not studied after second gassing.

and the result is a CO_2 acidosis. This condition would account both for the immediate moderate increase in the acidity in the urine after chlorine gassing, and for the high bicarbonate value in dogs which live for 24 hours. Since the high bicarbonate level means merely a compensating mechanism and not the removal of the cause of the pathological condition, one can understand the reason for the fact that not all animals survive whose bicarbonate level returns to normal or above.

The objections to the above interpretation are that it has not been possible to demonstrate in any case an increased content of CO_2 in venous blood after gassing, while it may be shown that the ratio $\frac{CO_2}{NaHCO_3}$ is adjusted in considerably less time than the theory demands. Still another possible explanation of the acidosis is the insufficient oxidation

TABLE LVIII *

The Influence of Sodium Bicarbonate Administration upon the Carbon Dioxide Capacity of the Blood

Dog No.	*Gas Conc. mgm. per liter*	*Hours after Exposure*	*Treatment*	*CO_2 Capacity*
92	0	0 (Normal)		47.0
	2.70	4		44.5
		4.5	100 cc. 5% $NaHCO_3$ per os	
		6.5		57.7
		9.5	100 cc. 5% $NaHCO_3$ per os	
		24.		63.3
96	0	0 (Normal)		52.8
	2.76	1		45.3
		1.5	3 gm. $NaHCO_3$ intravenously	
		4		57.6
97	0	0 (Normal)		66.7
	2.68	2	5 gm. Bicarb. per os	
		4¼		77.7
		6		74.0
		6¼	10 gm. Bicarb. per os	
98	0	0 (Normal)		51.0
	2.69	1	10 gm. Bicarb. per os	
		3		63.5
		3¼	5 gm. Bicarb. per os	
		24		61.6
		48		61.5
		100		65.4
100	0	0 (Normal)		61.4
	2.68	1		51.2
		1.25	Bled 150 cc. 3 gm. Bicarb. intravenously	
		5	5 gm. Bicarb. per os	
		24		66.3
		72		64.3
103	0	0 (Normal)		56.7
	2.69	2½		44.4
		3	Bled 150 cc. then 150 cc. 0.9% NaCl intravenously and 10 gm. Bicarb. per os	
		25		59.7

* The animals which furnished the data on bicarbonate administration were treated by various methods and the alkali therapy was only one part of the regular treatment. In all cases where bicarbonate was given, however, an increase in the CO_2 capacity was observed.

which results from aeration of the blood, the acid products of metabolism producing the characteristic acidosis.

It is obvious, however, that the data at hand are insufficient to offer at present a final solution of the acidosis problem, but it is probable that acidosis will prove to be a resultant of the operation of all three factors discussed.

The Hydrogen Ion Concentration of the Blood.

In addition to the determination of the acidity of the urine and the bicarbonate in the blood the hydrogen ion concentration of the blood is available as an indication of acidosis. The P_H of blood is normally 7.4 which means that there is a slight preponderance of hydroxyl ions (Table LIX). The "buffer" value of blood is high and it is only in extreme acidosis that the reaction, as shown by the hydrogen ion concentration, changes, hence a study of this factor gives us valuable data on the degree of acidosis.

TABLE LIX

Hydrogen Ion Concentration of the Blood after Chlorine Poisoning

Dog No.	*Gas Conc. mgm. per liter*	*Hours after Exposure*	*P_H of the Blood*	
			As Drawn	*After Blowing out CO_2*
4(1)	0	0(Normal)	7.4	8.2
	2.85	½	7.3	8.2
9	0	0(Normal)	7.45	8.2
	4.53	½	7.25	8.2
		2	7.35	8.2
		4	7.30	8.1
		6	7.30	8.0
12(1)	0	0(Normal)	7.4	8.2
	3.68	½	7.3	8.1
		2½	7.3	8.2
		4½	7.35	8.2
		26	7.45	8.2

The method of Levy, Rowntree and Marriott was used. The whole blood is dialyzed against a neutral physiologic saline solution and the P_H of the dialysate measured.

Whereas the P_H of normal blood is 7.4, after gassing the value falls to 7.3 and 7.25. When air is blown through the dialysate the value goes up to 8.2 in all cases. Although the drop from 7.4 to 7.25 is small numerically, in view of the high "buffer" value of the blood and the well-known fact that it is the last tissue to change in its chemical characteristics, the observed values indicate a severe upset of the acid-base equilibrium. In the dialysate all of the salts in the blood are present, including sodium bicarbonate and ionized carbonic acid, so that there is the same ratio $\frac{CO_2}{NaHCO_3}$ in the dialysate as in the blood. If now, after dialyzing, the CO_2 is blown out with air, the base formerly held as bicarbonate appears as the more alkaline carbonate. If, however, the acidosis is due to fixed acids, the blowing out does not affect the P_H; at least not to the extent observed. The fact that in every case the blowing out reduced the P_H to the same value, 8.2, indicates strongly that the acidosis is one caused by CO_2 rather than by fixed acids.

In brief, the blood picture after chlorine gassing is, on the basis of the data presented, as follows: the chlorine irritates the lung tissue, causing the bronchiolar musculature to contract and also edema to appear. As a result of the edema the blood concentrates. The curtailed aeration, resulting from the edema, the concentrated blood, and the bronchiolar muscle contraction, results in a low degree of oxygenation of the blood; it results also in the inability to get rid of the CO_2 with the consequent accumulation which gives rise to a temporarily diminished alkaline reserve and to an increased hydrogen ion concentration. The decreased rate of circulation results indirectly in a very low O_2 content of the venous blood. These altered conditions tend to return to normal in 24 hours.

The acid-base equilibrium in the blood is distinctly affected by gassing with phosgene, but in no definite direction. Whereas with chlorine there was invariably a drop in the bicarbonate value immediately after gassing, with phosgene the bicarbonate value dropped in some cases and increased in other cases. In a normal animal the bicarbonate value is constant, never varying more than two or three volumes per cent. In dogs gassed with phosgene the variations above and below normal were large, sometimes as much as ten volumes per cent. There was one definite tendency, however, and that was the drop in bicarbonate value as the animal approached death. This terminal acidosis was observed in all animals that died 10 or more hours after gassing. The P_H value varied only slightly with the change in bicarbonate, the final drop as the animal approached death being the only pronounced change (see Table LX, page 129).

We may conclude, then, that although phosgene causes a wide fluctuation in the bicarbonate value, there is no definite acidosis until the terminal stages. These appearances of acidosis must be referred, therefore, to the consequences of oxygen want in the terminal stages of phosgene poisoning and cannot be regarded as a *specific* action of the gas.

The data relative to chlorpicrin appear in Table LXI, page 132. There seems to be no marked effect of the gassing until some 8 hours after gassing. During the first 8 hours, the values fluctuate about the normal. The P_H determinations vary, in most cases, with the bicarbonate value. After the 8-hour period, there is a gradual decline in both values, probably indicating an acidosis condition, though in neither case did the animal die within 24 hours.

It appears, then, from the scant data on hand that there is no immediate acidosis following poisoning by lethal doses of chlorpicrin.

It may, therefore, be concluded that the lethal gases fall into two groups with respect to the production of acidosis. With chlorine there is evidence of an immediate carbon dioxide acidosis which later may become readjusted, whereas with phosgene and chlorpicrin acidosis is apparent only in the terminal stages of poisoning and can hardly be accepted as being a specific response of the action of the gases. It is much more reasonable to regard this acidosis as a terminal acidosis induced by the condition, general depression, of the animal.

TABLE LX

Plasma Bicarbonate Percentage and Hydrogen Ion Concentration in Blood of Animals Gassed with Phosgene

Dog No.	*Conc.*	*Hours after Gassing*	*Bicarb.* CO_2	
153	72	0	53.0	
		¼	55.1	
		1½	57.8	
		2½	57.7	
		3½	56.9	
		5	56.0	
		10	53.8	
		22	53.8	
		24	51.9	
		28½	53.2	
		46½	45.3	Died
154	70	0	48.6	
		1/12	56.0	
		1	58.9	
		2	57.8	
		3	59.6	
		4½	57.9	
		9½	53.8	
		21	51.9	
		24	52.8	
		27	52.2	
		46	56.7	Recovered
168	72	0	47.1	
		1/12	50.0	
		2½	51.0	
		5	49.0	
		10	53.0	
		22	51.9	
		24	54.9	
		27½	53.8	Recovered
167	71	0	48.9	
		¼	Blood clotted	
		½	48.1	
		3	52.8	
		5½	52.8	
		10½	51.9	Died
186	72	0	66.2	
		¼	70.1	
		8¼	73.9	
		20	64.4	Died

TABLE LX (Continued)

Dog No.	*Conc.*	*Hours after Gassing*	*Bicarb. CO_2*	*P_H before aeration*	*P_H after aeration*
266	76	0	67.1	7.4	7.9
		⅙	66.2	7.4	7.9
		4½	72.1		
		22	61.4	7.2	7.9
		24	43.3	7.2	7.9
285	77	0	55.9	7.4	8.1
		⅓	51.0	7.2	8.0
		5	55.1	7.4	8.1
					Died
177	62	0	61.6		
		¼	62.5		
		19½	58.6		
		21½	59.5		
		25	59.5		
		27	54.9		
		33	58.7		
		45	54.9		
		69	48.8		Died
185	68	0	70.0		
		1/12	73.9		
		9	80.5		
		21	80.6		Recovered
291	65	0	56.0	7.4	8.0
		0	56.9	7.4	8.1
		¼	59.7	7.4	8.1
		5	46.2	7.4	8.0
		22	57.6	7.4	8.1
		24	57.6	7.4	8.1
		28½	55.9	7.4	8.0
					Recovered
292	64	0	64.4	7.4	8.0
		⅙	65.4	7.4	8.0
		4½	60.5	7.4	8.1
		21½	50.0	7.4	8.1
		24	62.3	7.3	8.1
		28	62.3	7.4	8.0
					Recovered
236	63	0	62.4	7.4	8.1
		½	56.7	7.3	8.1
		4	61.4	7.3	8.1
		22	61.4	7.3	8.0
		24	58.6	7.4	8.0
					Recovered

TABLE LX (Continued)

Dog No.	*Conc.*	*Hours after Gassing*	*Bicarb. CO_2*		
259	84	0	54.7	7.3	7.8
		⅙	56.7	7.4	7.8
		3¼	60.4	7.4	7.9
					Died
195	100	0	55.6		
		⅓	56.7		
		2½	56.7		
		8½	58.6		Died
194	100	0	62.3		
		⅓	62.4		
		5	66.2		
		10	58.6		
		22	56.7		
		24	52.8		
		29	48.7		Died
202	100	0	64.2		
		1/12	63.3		
		4½	60.3		
		10	Tube broke		
		22	60.3		
		24	64.3		
		28½	67.3		
		34	66.2		Recovered
209	100	0	62.3		
		¼	62.4		
		4½	72.1		
		10	60.4		
		21	60.4		
		24	61.4		Died
215	100	0	61.4		
		1/12	56.7		
		6	65.3		
		10	58.6		
		12	58.6		
		24	44.3		Died

TABLE LXI

Plasma Bicarbonate Percentage and Hydrogen Ion Concentration in Blood of Animals Gassed with Chlorpicrin

Dog 401

	Bicarb. CO_2	P_H
Normal	67.3	7.7
Gassed 9:34 A.M.		
Immediately	67.2	7.6
½ hour	63.5	
1	68.2	7.7
2	69.2	8.0?
4	66.3	7.7
8	67.3	7.5
12	63.3	7.5
16	53.8	7.5
22	59.5	7.5
24	57.6	7.3?

Dog 419

	Bicarb. CO_2	P_H
Normal	62.4	none
Gassed 10:13 A.M.		
Immediately	63.3	7.7
½ hour	64.4	7.7
1	65.4	7.6
2	67.3	7.8
4	62.6	7.7
8	59.7	7.6
12	62.4	7.5
16	53.7	7.4
22	53.7	7.5
24	52.7	

CHAPTER XI

AN INTERPRETATION OF GAS POISONING

In the previous pages an outline has been given of the changes that occur in the organism as the result of exposure to the lethal gases. Restated briefly the gassing has a definite influence upon the respiration, pulse, temperature, blood concentration, water content of the lungs and tissues, chloride content of blood and tissues with resulting changes in chloride excretion by way of the kidneys, red and white cells and hemoglobin of the blood, distinct alterations in oxygen of the blood, leading to dyspnoea and partial asphyxia, the presence of acidosis at times, and a definite influence upon protein metabolism.

The effects of gassing as thus enumerated are so various and devious that an attempt toward correlation or the assignment of cause and effect seems at first glance well-nigh impossible. Further inspection of the data presented, however, brings to light one significant feature which stands out clear and distinct from all the other effects induced by exposure to gas. This is the well-defined curve of changes in blood concentration. Upon the basis of alterations in blood concentration quite definite stages in gas poisoning may be outlined. These stages stand out most clearly with phosgene and, therefore, the picture presented by this gas will be considered first.

Stages in Phosgene Poisoning.

First Stage.

In the first few hours (5 to 8) after phosgene poisoning there is a notable decrease in the concentration of the blood. The decreased concentration occurs rapidly and then the blood gradually tends to assume the normal concentration. In this period there may be a significant dilatation of the heart (observed by Eyster). Accompanying the decreased concentration of the blood there is a sharp drop in the chlorides of the blood and a marked increase in the chlorides and water content of the lungs. The chlorides of the urine increase immediately after gassing, reaching a maximum between the third and seventh hours, then decreasing. The heart beat is distinctly slowed at first with a tendency to regain the normal or be somewhat above normal before this period is over. The immediate effect upon the respiration is a distinct increase in the rate. During this period the temperature shows a marked increase, attaining a maximum coincident with the termination of this period. *Oxygen capacity, erythrocytes and hemoglobin follow a curve parallel with that of the changes in the concentration of the blood throughout all stages of phosgene poisoning.* Oxygen content of both arterial and venous blood decreases significantly. The saturation of hemoglobin with oxygen decreases somewhat. In general, the decrease is more marked in the venous than in the arterial blood. In the first period an influence upon protein metabolism is not noticeable.

Second Stage.

The period (5 to 8 hours) of blood dilution is followed by an interval during which the blood rapidly becomes concentrated to a point far beyond the normal value and remains near this level for several hours. In this stage the heart may be markedly decreased in size (Eyster). During the period of increased blood concentration the chlorides of the blood show a tendency to regain the normal. The water and chloride content of the lungs reach a maximum and then gradually fall. The urinary chloride excretion is normal or subnormal. The heart beat and respiration are both markedly accelerated.* The temperature, on the other hand, steadily decreases to a degree or more below normal. If the animal dies in this stage the temperature may fall steadily up to the time of death. *Most of the fatalities occur in this stage.* The oxygen content of arterial blood remains fairly stationary at a nearly normal value whereas that of venous blood falls rapidly to a very low level. The saturation of hemoglobin with oxygen decreases rapidly in both arterial and venous blood, but the fall is greater in venous blood. There is no evidence of an influence upon protein metabolism.

Third Stage.

After the period of increased concentration the blood gradually becomes more dilute until it is slightly under the normal value which is eventually gained and the animal recovers. The chlorides of the blood gradually tend to regain the normal level. The chloride and water contents of the lungs follow a similar course. In animals reaching this stage the heart beat and respiration rise to a maximum and then gradually attain the normal. The temperature rises to normal or above in those animals that eventually recover. In those animals that die during this period the heart beat and respiration rise, but the temperature steadily falls. The oxygen content of arterial and venous blood tends to regain the normal. Chloride excretion by the kidney is markedly decreased, but later is much augmented. Coincident with the increased chloride excretion is a noticeable increase in the protein metabolism.

The interpretation which may be placed upon the different stages of phosgene poisoning is as follows: In the first stage there is a marked dilution of the blood. There are at least two ways in which this dilution may be explained. In the first place, it may mean an increased blood *volume*, the excess fluid finding its way into the blood from the tissues in response to the strong irritative stimulus exerted by the gas upon the respiratory tract. Or secondly, a diluted blood would result if the red cells were removed in part and deposited in some organ or tissue. In the present investigations no studies have been made to determine actual changes in blood volume. Reports by Eyster and Meek, however, who have made such estimations tend to the conclusion that in the stage under discussion blood volume is not increased and they account for the dilution of the blood on the hypothesis that red cells are stored in the lungs, at least temporarily. Whichever explanation is correct it is certain that during this first stage two features may be quite prominent, namely, edema of the lungs and dilatation of the heart. Edema can be explained very readily on the hypothesis of increased blood volume and it is also possible that such a condition might lead to a dilated heart. On the other hand, the deposition of corpuscles in the lungs by causing an obstruction in the circulation would lead to a dilated right heart. The relatively large transport of fluid to the lungs during this period is, however, not so easily explained by this hypothesis. Whichever hypothesis is accepted edema of the lungs prevails and there may be a dilated right heart.

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*In animals that are in a serious condition although the rate of respiration is markedly increasing there is a decrease in depth so that rapid shallow breathing exists.

In the second period edema has reached its maximum development and here also blood concentration is at its height. The latter state is undoubtedly induced by the withdrawal of fluid which finds its way into the lungs. During the interval of blood concentration the blood volume is definitely decreased and the heart may be noticeably diminished in size (Eyster). This would presumably result in a decreased efficiency of this organ and lead to an inadequate circulation. Later, when the blood resumes its normal degree of concentration, normal heart action is reestablished.

The development of edema induces a mobilization of chlorides in the lungs at the expense of the chlorides of the blood, the lowered chloride content of which may also be explained in part by loss of chlorides through the kidneys, since at this period the output of chlorides in the urine is appreciably augmented. Later, during the second period, the chlorides of the lungs reach a maximum, the blood content is not called upon and, therefore, an approximately normal blood chloride content may be found which is maintained thereafter. This chloride retention by the lungs coincides with the fact that on the second day of phosgene poisoning the urinary excretion of chlorides is usually below normal. The period of readjustment now follows during which edema subsides in the lungs, and presumably both fluid and chlorides are demobilized by the lungs and find their way into the blood. The excess of chlorides over the normal in the blood is eliminated through the kidneys, which would account for the large output on the third day after gassing.

The changes in oxygen capacity, erythrocytes and hemoglobin follow the curve of alterations in blood concentration throughout the entire course of phosgene poisoning, which might well be anticipated. Oxygen content of arterial blood in general shows relatively unimportant changes, whereas that of venous blood progressively diminished throughout the first and second periods of phosgene poisoning. This may be explained in the first period by the fact of diluted blood and in the second period is undoubtedly caused by the longer contact of the blood with the tissues, induced by an inefficient circulation.

The respiratory changes are correlated with the impaired respiratory functions of the blood such as lowered oxygen content and incomplete saturation of the hemoglobin with oxygen.

In the first period decreased heart rate may be explained best, perhaps, on the hypothesis of nervous inhibition. The later rapid pulse is directly induced by the viscous character of the blood which causes oxygen want. Although specific data are lacking it appears quite evident that there is a distinct fall of blood pressure. One may assume a direct relationship between the heart's efficiency and temperature. Thus, in the first part of the first period the heart action is slow, there is inefficient circulation, and the temperature falls. Later, the greatly accelerated pulse is accompanied by a rise in temperature far above the normal. From this it would appear possible that the heart has temporarily overcompensated resulting in an efficiency of the circulation above the normal level.

Now follows the period of concentration of the blood. This concentrated blood is, without doubt, more difficult to circulate through the body and if the heart is only doing its normal work there will be, as a result of the thickened blood, a circulation of less than normal efficiency and such a condition apparently results in a falling temperature. In case the heart responds with a much higher rate during the period of concentration so that even with the thickened blood it appears that a circulation of close to normal efficiency is being maintained it will be found that the temperature is also well maintained.

In the animals which are less seriously affected and in which only a slight edema of the lungs develops, with a consequent slight loss of fluid from the blood, it will be found that the temperature is well maintained provided the heart rate is normal. However, even in such cases the continuous, even though slight, loss of fluid from the blood will eventually result in a concentration of the blood which will bring the circulation below normal efficiency, even with a high pulse rate, and the temperature will slowly drop until at about the 24th hour it is about 1° C., below normal. On the other hand, in the animals which are seriously affected, the blood concentrates very rapidly. The heart, even though the rate is maintained far above normal, is nevertheless not able apparently to maintain a circulation of normal efficiency, the temperature drops very rapidly and the animal dies within less than 24 hours after gassing.

In brief, then, it seems plausible that the temperature is directly related to the efficiency of the circulation and this in turn is determined, in part at least, by the concentration of the blood and the pulse rate.

This view appears to be further strengthened by the results obtained from the study of animals gassed with chlorpicrin and chlorine. In both of these cases there is, in general, a state of concentration of the blood beginning immediately after gassing. Only in rare instances does a dilution of the blood occur and then it is only for a short time. From the first, then, in animals poisoned with these gases there obtains a condition in which the blood is above normal in concentration and in correspondence with this the temperature stays below normal and the more seriously the animal is affected and the greater the concentration of the blood, the greater will be the fall in temperature.

Phosgene poisoning has been considered in detail since it is unique in showing among its effects the initial period of blood dilution. At times chlorpicrin presents a similar stage, but this interval is never so pronounced either in degree or length as obtains in phosgene poisoning. Usually a preliminary dilution period is lacking. It is this period that undoubtedly gives to phosgene the distinction of possessing a so-called "delayed action." Chlorine gas rarely, if ever, causes a period of blood dilution. In general, if one should consider the changes in blood concentration outlined for phosgene minus the initial dilution period the remaining curve would represent fairly accurately the alterations occurring in the blood in both chlorine and chlorpicrin poisoning. This would, of course, entail differences in *time* relationships, but under the conditions noted the changes in blood concentration of chlorine and chlorpicrin would be accompanied by the same general type of effects which are obtained with phosgene. Under these circumstances it appears superfluous to recite further the correlation of the effects of chlorine and chlorpicrin poisoning.

The Cause of Death in Gas Poisoning.

It is generally assumed that the cause of death in gas poisoning is due directly to edema of the lungs aided, of course, by the accompanying congestion. It has been said that death is caused by an individual literally drowning in the water of his lungs. The quantity of water present may reach as high a figure as a liter or more and such a conception as the cause of death seems quite obvious. On the other hand, one may well ponder whether death is usually induced in this way or whether there may be some other cause to which one may point with more certainty. The most obvious condition, other than edema, which could lead to death is the concentration of the blood. Of course, it is evident that edema and blood concentration are closely associated. Edema is assuredly the cause for blood concentration and thus indirectly at least brings about death, but it would appear that blood concentration is much more likely to produce death than is the presence of fluid in the lungs. There are, therefore, two possibilities open.

Death by edema could be caused by the prevention of an adequate oxygen exchange in the pulmonary blood. On the other hand, through extensive experiments of Winternitz,* it is quite possible to introduce large quantities of fluid directly into the lungs of normal dogs without causing death, the fluid being absorbed with surprising rapidity. It must be conceded, however, that the conditions obtaining in the lungs of a normal dog and in those of a gassed animal are quite different, for in the experiments cited simple salt solution was introduced whereas in an edematous lung the fluid more nearly represents blood plasma. Such a fluid would have a much greater tendency to inhibit adequate oxygen exchange than would a simple salt solution. The adherents of the idea that edema is the cause of death must ascribe death to asphyxiation. There is little doubt that well-developed edema does interfere with oxygen exchange of the pulmonary blood, but usually the efficiency of the arterial blood as an oxygen carrier is surprisingly high. It would seem a simple matter to put the question to the test experimentally. Thus, it might be assumed that if edema is the cause of death, this operating by producing asphyxia, administration of oxygen should save the animal provided the oxygen could be absorbed. Such experiments have been carried through in this investigation and the results have demonstrated that, even though the oxygen in the arterial blood may be raised and maintained in the higher normal limits, death intervenes as usual. Then again, some animals seem to die with much less edema than others and the different gases also possess different degrees of ability in provoking edema. If edema is the cause of death it is difficult to explain why some animals with an apparent excessive quantity of fluid in the lungs should survive. Death is caused by something more than simple inability of the blood to absorb oxygen, by something more than a physical obstacle in the lungs.

It seems quite logical to assume that blood concentration is immediately responsible for death. Blood concentration means a failing circulation, an inefficient oxygen carrier, oxygen starvation of the tissues, fall of temperature, and finally suspension of vital activities. The whole aim of treatment has been to prevent blood concentration or else restore it to the normal level. When this is accomplished the animal survives in spite of the fact that the lungs may be very edematous. It may be stated, then, that in the presence of edema and a concentrated blood, entrance of oxygen into the circulation does not prevent death. On the other hand, restoring blood to the normal concentration enables an animal to survive even though an extensive edema exists. Administration of oxygen under the last named conditions undoubtedly makes recovery easier.

Therefore, while it is accepted that indirectly the edema of gas poisoning results in death, the *immediate cause* of death must be assigned to blood concentration.

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*Unpublished.

CHAPTER XII

THE TREATMENT OF CHLORINE POISONING

In chlorine poisoning gassed dogs fall naturally into two chief classes: dogs which die within three days (acute deaths) as a result of changes directly induced by the gas; and dogs which survive this acute period (survivals) and recover or later succumb to secondary factors, chiefly pneumonia. It is obvious that in the treatment of chlorine poisoning attention should be focused on the prevention or alleviation of the acute effects—the direct results of the action of the chlorine—and the success of the treatment should be judged from the point of view of the total number of survivors, that is, those living through the acute period rather than from actual recoveries, since the factors, infection, etc., which prevent the recovery of most of the survivors are merely incidental to the gassing.

In this investigation it was imperative frequently to draw samples of blood after gassing. Though the quantity of blood drawn at any one time was small, it was noted that many of the animals seemed to be favorably influenced by the experimental procedure.

Venesection, of course, has long been employed in conditions involving pulmonary edema and congestion. Recently, it has been applied, with conflicting results, in the treatment of these conditions induced in man by poisonous gases in warfare. Inasmuch as the incidental observations with blood-letting indicated a favorable influence upon gassed dogs, it was deemed desirable to determine under exact conditions the effect of venesection upon the mortality of dogs receiving a lethal concentration of chlorine gas.

A. *Effect of Venesection Alone.*

A series of twenty dogs, which had been gassed by the standard method (see Appendix to Chapter II, page 183), were studied to determine the effect of venesection on chlorine poisoning. Blood to the amount of not less than 1 per cent of the body weight was drawn from each animal soon after exposure. It was assumed, on account of the rapid development of serious symptoms, that it was imperative to treat the animals as soon as practicable after gassing. Obviously it is easier to inhibit the establishment of an abnormal state than to alleviate the condition when fully established. However, variations up to two hours in the time of treatment apparently play little rôle in its efficacy.

The blood was drawn, without anesthesia, by aspiration through a needle inserted through the skin into a jugular vein. This procedure is carried out easily and without discomfort to the animal. In most cases the blood was drawn all at one time, but in a few instances it was removed by several small bleedings. In either case the general result was the same, as was determined by separate analysis of the data, and accordingly all the data are included together in Table LXII. The standard toxicity figures are given for comparison. It is apparent from the table that 35 per cent of the animals which had been bled survived the acute period as compared with 13 per cent survivals for the untreated animals.

The percentage of dogs that died acutely is decreased from 87 per cent to 65 per cent. These figures indicate clearly the therapeutic value of venesection after chlorine poisoning in dogs under the conditions of the experiment.

TABLE LXII

EFFECT OF VENESECTION ON CHLORINE POISONING AFTER STANDARD GASSING

	*Untreated**	*Bled 1% or More of Body Weight*
Percentage of Deaths		
1st Day	52	40
2nd Day	26	15
3rd Day	9	10
Total Acute Deaths	87	65
Delayed Deaths	4	5
Recoveries	9	30
Survivals	13	35
Number of Dogs	23	20

*Cf. Table I, page 7.

The result is at variance with that reported by British investigators upon goats. But it should be emphasized in the present experiments upon dogs that the bleeding was performed early (usually from ½ to 2 hours after gassing) and, therefore, before the onset of severe symptons. At times we have observed experimental animals die acutely during treatment. In all cases, however, the animal struggled violently and in several instances death occurred before any attempt was made at manipulative procedure, bleeding or otherwise. Under these conditions it would seem that the observed collapse was caused by failure of the heart, a resultant of violent struggling rather than venesection. Furthermore, it should be observed in this connection that the conclusions reached are based on the actual death or survival of the animals experimented on and that the gassing procedure was carried out under carefully controlled conditions which permit accurate comparison with previously determined toxicity figures.

B. *Effect of Venesection plus Infusion.*

Having established the therapeutic value of venesection, attempts were made to determine measures to still further increase the percentage of survivals. Infusion of physiologic salt solution is distinctly indicated when large volumes of blood are withdrawn. Under these circumstances the salt solution tends toward the temporary maintenance of the normal blood volume and helps to maintain in equilibrium other important functions. Furthermore, the thickened condition of the blood subsequent to gassing suggested the infusion for its probable diluent effect. Therefore, a series of fifteen gassed dogs were bled 1 per cent of body weight and immediately thereafter were infused with warm isotonic sodium chloride solution, equal in volume to the blood withdrawn. The infusion was accomplished by inserting a needle under aseptic conditions through the skin into the jugular vein. The solution was allowed to flow slowly from a burette.

The results (Table LXIII) show 40 per cent of survivals as compared with 35 per cent survivals for venesection alone, and 13 per cent for the untreated series. Conversely the acute deaths are reduced to 60 per cent as compared with 65 per cent for venesection alone and 87 per cent for the untreated dogs.

TABLE LXIII

Effect of Venesection and Infusion of Salt Solution

Treatment	*Untreated (Standard Toxicity)*	*Bled*	*Bled and Infused Isotonic NaCl*
Percentage of Deaths			
1st Day	52	40	60
2nd Day	26	15	
3rd Day	9	10	
Total Acute Deaths	87	65	60
Delayed Deaths	4	5	20
Recoveries	9	30	20
Survivals	13	35	40
Number of Dogs	23	20	15

A closer analysis of the data, however, for each of the three days which comprise the acute period is suggestive. It will be noted that, while *both* bleeding alone and bleeding plus infusion markedly reduced the total acute deaths (deaths during first three days) as compared with those in the untreated series, and while bleeding plus infusion showed a greater reduction in this regard—and, therefore, is more efficacious judged by the standard of this investigation than bleeding alone, nevertheless bleeding plus infusion shows a much greater number of deaths during the first 24 hours and no deaths during the remainder of the acute period. In other words, the infused NaCl apparently has had a deleterious effect on the most severely poisoned dogs, *i.e.*, the dogs which if untreated would have succumbed acutely, in that it has brought about the death of all within the first 24 hours after exposure, while it has had a *decidedly beneficial* effect on another group of animals—presumably less severely affected by the gas—and has successfully tided them over the three-day period and put them into the group of survivals.

Therefore, the results from this experiment establish beyond peradventure that venesection is a valuable therepeutic measure and indicate that venesection plus infusion of NaCl is better. Furthermore, the analysis of data for the respective 24-hour periods suggests that measures must be sought to save at least the percentage of untreated animals which are forced, as it were, from the latter part of the acute period into the first 24 hours.

Accordingly, the effect of substituting the infusion of isotonic acid, alkaline and neutral solutions of other salts in place of sodium chloride was investigated. The chief results are given in Table LXIV, from which it is apparent that both Na_2HPO_4 and Na_3PO_4 gave at least as high a percentage of survivals as sodium chloride. But Na_3PO_4, as well as NaH_2PO_4, gave rise to marked respiratory disturbances and so were not considered further. Na_2HPO_4, however, offered a suggestive lead since this alkaline solution gave a slightly higher percentage of survivals than sodium chloride.

TABLE LXIV

Influence of Various Salt Solutions in the Treatment of Chlorine Poisoning

			Bled and Infused Isotonic				
Treatment	*Untreated*	*Bled*	*(I)* *NaCl*	*(II)* *Na_2HPO_4*	*(III)* *NaH_2PO_4*	*(IV)* *Na_3PO_4*	*(V)* *Neutral Mixture*
Percentage of Deaths							
1st Day	52	40	60	43	67	40	74
2nd Day	26	15		14		20	10
3rd Day	9	10					10
Total Acute Deaths	87	65	60	57	67	60	94
Delayed Deaths	4	5	20	14		20	
Recoveries	9	30	20	29	33	20	6
Survivals	13	35	40	43	33	40	6
Number of Dogs	23	20	15	14	6	10	19

(I) 0.85–1.0% NaCl
(II) 4.5% $Na_2HPO_4 .12 H_2O$
(III) (1 cc = 5.00 mgm. P)
(IV) (1 cc = 4.00 mgm. P $\Delta = -57$)
(V) P_H 7.4 Solutions *not* isotonic

C. *Effect of Venesection, Infusion and Administration of Sodium Bicarbonate.*

It has been shown in the investigation of the urine after chlorine poisoning that a characteristic increase of acidity and augmented excretion of ammonia, acid phosphates, and organic acids occur. All of these indicate acidosis. In addition, this is substantiated by the direct determination of the bicarbonate value of the blood. Since alkali administration is suggested in all conditions where an acidosis is present, a study was made of the influence of sodium bicarbonate (5–10 grams in 50–200 cubic centimeters of water) per os, in conjunction with venesection and infusion of sodium chloride.

The results on a series of 28 dogs are summarized in Table LXV. The animals given the sodium bicarbonate after bleeding and infusion show a distinctly greater percentage of survivals, 54 per cent as compared with 40 per cent for those merely bled and infused. Also, the latter series shows 60 per cent acute deaths while the bicarbonate-treated series shows only 46 per cent acute deaths. It is to be noted again, however, that there is still the tendency, though by no means so marked, for acute deaths to be forced, as it were, from the later to the early part of the three-day acute period—there being yet more acute deaths during the first day after gassing followed by bleeding plus infusion and bicarbonate than after bleeding alone—though the net result of the former method is decidedly *more* beneficial.

TABLE LXV

Treatment of Chlorine Poisoning

Treatment	*Untreated*	*Bled*	*Bled and Infused Isotonic NaCl*	*Bled and Infused Isotonic NaCl $NaHCO_3$ per os*
Percentage of Deaths				
1st Day	52	40	60	43
2nd Day	26	15		3
3rd Day	9	10		
Total Acute Deaths	87	65	60	46
Delayed Deaths	4	5	20	25
Recoveries	9	30	20	29
Survivals	13	35	40	54
Number of Dogs	23	20	15	28

From the investigation of therapeutic measures as thus far outlined, it is clear, we believe, that bleeding is beneficial; that bleeding plus infusion of isotonic sodium chloride solution is more beneficial; and that bleeding and infusion plus the administration of sodium bicarbonate per os is most beneficial, since, under the conditions of the experiment, 54 per cent of animals survived after the latter treatment as compared with 13 per cent of survivals for the untreated series.

D. *Effect of Various Modifications of the Treatment.*

Attempts were then made to improve the treatment further by an investigation of the effects: (1) variations in the concentration of the infused sodium chloride solution, (2) variations in the volume of the infused sodium chloride solution, (3) the infusion of isotonic non-electrolytes, (4) the substitution of other infusion fluids for the sodium chloride, (5) other methods.

1. Variations in the concentration of the NaCl infusion fluid. Forty dogs were given the treatment outlined above except that the concentration of the sodium chloride solution was slightly hypo- or hypertonic. The results (Table LXVI) show at a glance that the infusion of the slightly hypotonic and hypertonic solution of sodium chloride is markedly inferior to isotonic solutions, the survivals varying from 16 per cent to 35 per cent for the former as compared with 54 per cent for the latter. In fact, non-isotonic infusion is less beneficial than venesection without infusion at all. *Emphasis, therefore, should be placed upon the necessarily narrow limits of concentration allowable in the infusion fluid.*

2. Variations in the volume of the infused sodium chloride solution. Twenty-eight dogs were studied in order to determine whether the infusion of smaller or larger volumes of sodium chloride solution than the volume of the blood (1 per cent of body weight) withdrawn would improve the treatment. In this series sodium bicarbonate was *not* administered. Comparing the figures obtained with those for one volume of sodium chloride

infusion without bicarbonate administration shows unquestionably that infusion of more or less solution than blood withdrawn is far less beneficial (Table LXVII). Experiment also demonstrated (Table LXVIII) that repeating the saline infusion 7 to 10 hours after the first treatment does not increase the percentage of survivals above the figure obtained by single treatment.*

*Note that in this experiment $NaHCO_3$ was administered.

TABLE LXVI

THE INFLUENCE OF VARIOUS STRENGTHS OF SODIUM CHLORIDE SOLUTIONS IN THE TREATMENT OF CHLORINE POISONING

			Bled plus $NaHCO_3$ per os Infused NaCl Solution			
Treatment	*Untreated*	*Bled*	*Isotonic* *0.95–1.0%*	*Hypotonic* *0.7%*	*Hypertonic* *1.3%*	*1.75%*
Percentage of Deaths						
1st Day	52	40	43	57	50	67
2nd Day	26	15	3	7	14	17
3rd Day	9	10		7		
Total Acute Deaths	87	65	46	71	64	84
Delayed Deaths	4	5	25	29	21	8
Recoveries	9	30	29		14	8
Survivals	13	35	54	29	35	16
Number of Dogs	23	20	28	14	14	12

TABLE LXVII

THE INFLUENCE OF THE VOLUME OF FLUID INJECTED IN THE TREATMENT OF CHLORINE POISONING

	Bled and Infused Isotonic NaCl Solution		
Treatment	*1 volume*	*½ volume*	*2 volumes*
Percentage of Deaths			
1st Day	60	45	65
2nd Day		27	6
3rd Day		9	6
Total Acute Deaths	60	82	76
Delayed Deaths	20	9	6
Recoveries	20	9	18
Survivals	40	18	24
Number of Dogs	15	11	17

TABLE LXVIII

The Influence of Repeated Infusion in the Treatment of Chlorine Poisoning

	Bled, $NaHCO_3$ per os Infused Isotonic NaCl Solution	
Treatment	*One Infusion*	*Infusion Repeated*
Percentage of Deaths		
1st Day	43	37
2nd Day	3	16
3rd Day		5
Total Acute Deaths	46	58
Delayed Deaths	25	21
Recoveries	29	21
Survivals	54	42
Number of Dogs	28	19

3. Infusion of isotonic non-electrolytes. The infusion of solutions of non-electrolytes such as isotonic dextrose alone and 3 or 6 per cent gum acacia in isotonic saline (1 to 3 infusions) was also found to increase the acute mortality as well as decrease the survivals as compared with the standard toxicity figures for untreated animals (Table LXIX).

4. Substitution of other infusion fluids for isotonic sodium chloride. A series of thirteen dogs was infused with Ringer's solution with double the usual amount of calcium. Another series of fifteen dogs was infused with isotonic Na_2SO_4. Both of these fluids were markedly less beneficial than isotonic NaCl (cf. Table LXX).

5. Other procedures tested. Morphine (5 mgm. per kilo) was administered to ten dogs in addition to the prescribed treatment and found to be distinctly harmful. In this series the survivals were only 10 per cent as compared with 54 per cent for dogs receiving the regular treatment alone and 13 per cent for untreated animals (Table LXXI). Another series of eighteen animals was treated in an entirely different manner. To eight dogs 5 to 10 grams of $NaHCO_3$ was administered by stomach sound—bleeding and infusion being omitted. This treatment was without beneficial effect (Table LXXII), the total acute deaths and the survivals being the same as for untreated animals. The ten other dogs of the series were merely bled 1 per cent and then given a subcutaneous infusion of 1 per cent calcium chloride in 0.5 per cent sodium chloride solution according to the method outlined in the "Translation of Captured German Document." This procedure was found to increase the percentage of total acute deaths and decrease the percentage of survivals as compared with that for animals which receive no treatment whatsoever (Table LXXII).

TABLE LXIX

THE INFLUENCE OF DEXTROSE AND ACACIA SOLUTIONS IN THE TREATMENT OF CHLORINE POISONING

		Bled, $NaHCO_3$ per os Infused			
Treatment	*Untreated*	*Isotonic NaCl*	*Dextrose 5.5%*	*Acacia 6% Isotonic NaCl*	*Acacia 3% Isotonic NaCl*
Percentage of Deaths					
1st Day	52	43	73	43	67
2nd Day	26	3	27	58	
3rd Day	9				11
Total Acute Deaths	87	46	100	100	78
Delayed Deaths	4	25			
Recoveries	9	29			22
Survivals	13	54			22
Number of Dogs	23	28	11	7	9

TABLE LXX

THE INFLUENCE OF CALCIUM AND OTHER SALTS IN THE TREATMENT OF CHLORINE POISONING

		Bled plus $NaHCO_3$ per os Infused		
Treatment	*Untreated*	*Isotonic NaCl*	*Ringer's Solution Double Calcium Content*	*Isotonic 2% Na_2SO_4*
Percentage of Deaths				
1st Day	52	43	77	60
2nd Day	26	3		7
3rd Day	9		15	7
Total Acute Deaths	87	46	92	74
Delayed Deaths	4	25	8	7
Recoveries	9	29		20
Survivals	13	54	8	27
Number of Dogs	23	28	13	15

TABLE LXXI

Effect of Morphine in Treatment of Chlorine Poisoning

Treatment	*Untreated*	Bled, $NaHCO_3$ per os Infused: *Isotonic NaCl*	Bled, $NaHCO_3$ per os Infused: *Isotonic NaCl plus Morphine (0.5 mgm. per kilo)*
Percentage of Deaths			
1st Day	52	43	60
2nd Day	26	3	30
3rd Day	9		
Total Acute Deaths	87	46	90
Delayed Deaths	4	25	
Recoveries	9	29	10
Survivals	13	54	10
Number of Dogs	23	28	10

TABLE LXXII

The Influence of Subcutaneous Injections of Calcium in the Treatment of Chlorine Poisoning

Treatment	*Untreated*	*Bled Infused Isotonic NaCl $NaHCO_3$ per os*	*$NaHCO_3$ per os*	*Bled 1% $CaCl_2$ in 0.5% NaCl Solution subcutaneously*
Percentage of Deaths				
1st Day	52	43	63	60
2nd Day	26	3	12	30
3rd Day	9		12	
Total Acute Deaths	87	46	87	90
Delayed Deaths	4	25		10
Recoveries	9	29	12	
Survivals	13	54	12	10
Number of Dogs	23	28	8	10

E. *Effect of Environmental Conditions (Temperature) on the Efficacy of the Prescribed Treatment.*

Finally, a study was made of the effect of environmental conditions, chiefly temperature, on the efficacy of the prescribed treatment. Throughout the definitive experiments, every endeavor was made to keep the gassed animals under as favorable conditions as possible. However, one series of ten dogs was allowed to become chilled after exposure to the gas, and another series of nine dogs was kept at a relatively low temperature. Both series received the prescribed treatment. The data (Table LXXIII) show 20 per cent survivals for the "chilled," and zero survivals for the "cold" series as compared with 54 per cent survivals for the regular series kept under favorable temperature conditions. The result is a conclusive demonstration of the important part played by external temperature in determining the survivals and recoveries after gassing.

TABLE LXXIII

Effect of Environmental Conditions (Temperature) on the Efficiency of the Prescribed Treatment

	Bled and Infused Isotonic NaCl $NaHCO_3$ per os		
Treatment	*Kept warm*	*Chilled*	*Cold*
Percentage of Deaths			
1st Day	43	70	100
2nd Day	3	10	
3rd Day	0	0	
Total Acute Deaths	46	80	100
Delayed Deaths	25	20	
Recoveries	29		
Survivals	54	20	0
Number of Dogs	28	10	9

F. *Summary of Studies on Treatment.*

The described investigation of therapeutic measures for chlorine poisoning has involved the study of over 300 dogs gassed at the standard lethal concentration as worked out in this laboratory. From the data presented in Chapter II on Toxicity it is apparent that the acute symptoms of chlorine poisoning are most prominent in dogs gassed at this concentration.

Therefore, it must be emphasized that the intensive changes induced by this lethal concentration put to the most rigorous test any method of treatment of the condition. A treatment which is reasonably successful at this lethal concentration may be expected to produce much greater results when administered in conditions less severe; that is, in animals exposed to lower concentrations of chlorine gas.

Again, environmental conditions, such as temperature, are crucial factors in determining the efficacy of therapeutic measures.

Over twenty different therapeutic procedures have been tried. These may be classified, on the basis of the data already presented, as follows:

1. *Distinctly beneficial.* a. Bleeding, infusion of isotonic NaCl solution in volume equal to the blood withdrawn, administration of $NaHCO_3$ by stomach sound (Table LXVI).

b. Bleeding, infusion of isotonic Na_2HPO_3 solution (Table LXIV).

c. Bleeding alone (Table LXII).

2. *Less beneficial or without beneficial effect.* a. Bleeding, infusion of hypertonic or hypotonic NaCl solution, $NaHCO_3$ by mouth (Table LXVI).

b. Bleeding, infusion of isotonic NaCl solution repeated 7 to 10 hours after the original treatment, $NaHCO_3$ by mouth (Table LXVIII).

c. Bleeding, infusion of isotonic NaCl solution in one-half or double the volume of the blood withdrawn (Table LXVII).

d. Bleeding, infusion of isotonic NaH_2PO_4 or Na_3PO_4 solution (Table LXIV).*

e. Bleeding, infusion of isotonic Na_2So_4 solution, $NaHCO_3$ by mouth (Table LXX).

f. Administration of $NaHCO_3$ by stomach sound (Table LXXII).

3. *Distinctly harmful.* a. Bleeding, infusion of isotonic NaCl solution, $NaHCO_3$ by mouth, morphine (0.5 mgm. per kilo) (Table LXXI).

b. Bleeding, infusion of isotonic dextrose solution, $NaHCO_3$ by mouth (Table LXIX).

c. Bleeding, infusion of 3 or 6 per cent gum acacia in isotonic saline solution, $NaHCO_3$ by mouth (Table LXIX).

d. Bleeding, infusion of neutral PO_4 mixture (Table LXIV).

e. Bleeding, subcutaneous infusion of 1.0 per cent $CaCl_2$ in 0.5 per cent NaCl (Table LXXII).

f. Bleeding, infusion of Ringer's solution with double quantity of calcium, $NaHCO_3$ by mouth (Table LXX).

Therefore, the investigation leads unmistakably to the conclusion that, under the conditions of the experiments, the first therapeutic method of those listed as "distinctly beneficial" is the one on which emphasis should be placed. This prescribed method may be restated as follows:

(1) Venesection, involving the withdrawal of approximately 1 per cent of the body weight. (2) Intravenous infusion of warm sterile isotonic solution equal in volume to the blood withdrawn. (3) Administration of $NaHCO_3$ by a stomach tube—5 to 10 grams in 50 to 200 cubic centimeters of water. Treatment to be carried out from one-half to two hours after exposure to the gas.

G. *Application of the Prescribed Method of Treatment to Man.*

The prescribed method of treatment of gassed animals may be applied directly to man. Each of the procedures adopted in the method has the endorsement of clinical experience in the treatment of the conditions involved.

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*The figures indicate a large increase in survivals, as compared with the untreated animals, but marked respiratory disturbances rendered the use of these salts inadvisable.

Venesection has long been used in conditions involving pulmonary edema and congestion. Recently, it has received application in the treatment of these conditions induced in man by poisonous gases in warfare.

The infusion of salt solution is distinctly indicated when large volumes of blood are withdrawn from the body. Infusion of salt solution under these conditions tends toward the temporary maintenance of the normal blood volume and helps to maintain in equilibrium other important functions. An additional reason for the injection of fluid in gassed animals is its probable diluent effect upon the thickened blood frequently encountered in gas poisoning.

Alkali administration is indicated in all conditions where an acidosis is present. Acidosis is present in dogs subjected to the action of chlorine. The dog is an animal particularly resistant to a condition of acidosis, while, on the other hand, man is more or less susceptible to a condition of acidosis. Inasmuch as the dog develops acidosis in gas poisoning it is probable that the degree of acidosis induced in man would be a very significant factor in the pathological state induced by the poisonous gas. Under these circumstances the administration of the proper quantities of sodium bicarbonate is recommended. It is also evident that the additional water entering the body by way of the mouth would be distinctly beneficial by tending to prevent the development of a highly concentrated blood.

The method of treatment is especially recommended because it is simple and harmless, and because it is based upon clinical usage and experimental evidence.

In the investigations which have provided the data from which the prescribed therapeutic method has been evolved, the success of the treatment has been judged by the number of survivals rather than by the number of recoveries, since the survivals represent the dogs which have withstood the direct effects of the gas.

The survivals, on the other hand, which do not recover ("delayed deaths") succumb in nearly every instance to indirect effects of the gas, chiefly broncho-pneumonia. These same indirect effects of gas poisoning have been repeatedly emphasized in reports of the clinical study of men in the war zone. For obvious reasons in experimental work on dogs it is impracticable, if not absolutely impossible, to afford each dog the adequate prophylactic measures which modern medical procedures afford man. Accordingly, it is reasonable to believe that the prescribed method of treatment, when administered to man, and followed by adequate prophylactic measures to combat the secondary clinical effects, chiefly broncho-pneumonia, should prove even more efficacious than it has proved to be for dogs. That is, the number of survivals and recoveries may be practically identical.

It has proved impossible to test the influence of the prescribed therapeutic measures directly on man inasmuch as chlorine gas had been practically abandoned as a war measure at the period when the method of treatment had become established.

CHAPTER XIII

THE TREATMENT OF PHOSGENE POISONING

It was not until a study of phosgene poisoning was made that an adequate conception was obtained of the fundamental principles involved in gas poisoning. The treatment for chlorine poisoning was evolved by more or less empirical methods, whereas in the case of phosgene the changes taking place in the blood were well recognized and the stages of phosgene poisoning quite clearly defined previous to any extensive attempts at therapeutic measures. This understanding of the problem led to a much more rational plan of attack with regard to treatment.

It is of interest that the treatment for phosgene formulated on this plan is in principle the same as outlined for chlorine poisoning except that *the time factor varies.* With chlorine poisoning early bleeding and early infusion of salt solution were advocated. With phosgene early bleeding and *late* infusion are imperative. With chlorine a significant acidosis was present, hence alkali by mouth was indicated. Inasmuch as acidosis fails to be manifested in phosgene poisoning except as a terminal acidosis the administration of sodium bicarbonate is omitted.

Since the time of infusion is directly indicated by the abnormally high concentration of the blood a rapid method of determining blood concentration is essential. It has been shown previously that blood concentration and hemoglobin content follow similar courses. Determination of hemoglobin, therefore, gives an exact indication of blood concentration and hence a means of determining when salt infusion should be made in order to restore concentrated blood to more normal conditions. A further aid to indicate the condition of the animal are the temperature changes which should be followed at one-half hour periods.

Treatment of First Stage of Phosgene Poisoning.

Approximately one hour after gassing blood is drawn from a vein to the extent of 1 per cent of the body weight. Bleeding at any time up to four hours after gassing is beneficial, but the best results are obtained when the withdrawal of blood is practiced about one hour after gassing.

Treatment of Second Stage of Phosgene Poisoning.

In the first stage blood concentration may exhibit one of two features after bleeding: (a) the blood becomes markedly dilute and *slowly* returns to normal concentration, (b) there is no significant dilution of the blood. The latter is an exceptional condition. The time of treatment will, therefore, depend upon which of these two conditions obtains. When the blood becomes markedly dilute and then *slowly* returns to the normal, infusion of 0.97 per cent NaCl solution, equal in amount to the blood withdrawn, should be practiced when the concentration reaches the normal level. This usually takes from 8 to 10 hours. On the other hand, when even after bleeding the concentration of the blood is not definitely decreased, infusion of salt solution should be delayed until there is a clear indication that the blood is becoming concentrated. This usually occurs from 6 to 8 hours after gassing. In any case the *infusion should not be delayed beyond the point where the blood has reached a concentration of more than 25 per cent above normal.*

In following blood concentration estimations of hemoglobin are made at intervals of an hour.

After the infusion of salt solution the concentration of the blood is followed at one hour intervals in order to determine whether subsequent salt infusions are indicated. In general after the first infusion the blood may begin to concentrate again within one hour and when this concentration continues it may be desirable to infuse subsequently, but judgment must be exercised in order to strike a proper mean between insufficient and excessive infusion. Insufficient infusion leaves the blood concentrated. Excessive infusion augments edema. So long as the concentration of the blood remains constant, infusion is unnecessary, and when the concentration diminishes the animal is on the road to recovery.

Treatment of Third Stage of Phosgene Poisoning.

Usually rest and warmth are all that are necessary in this stage, but if the blood should become greatly diluted again and remain so a second bleeding may be necessary. This condition, however, rarely occurs.

Observations Leading to Method of Treatment.

The adoption of early bleeding as a therapeutic measure in phosgene poisoning was made with the idea that it would be beneficial in preventing excessive dilution of the blood and would relieve the heart of the strain placed upon it by a significantly increased blood volume. This view was adopted previous to actual determinations of blood volume. It will be remembered that Eyster and Meek claim blood volume is not increased. If this is true then bleeding early plays little rôle with regard to the original conception. However, it is quite possible to interpret the beneficial effects of bleeding on the assumption that thereby pulmonary edema is modified in that extraction of considerable quantities of blood makes it more difficult for the organism to obtain from its tissues fluid sufficient to furnish an intensive edema. In other words one must assume that bleeding tends to delay or inhibit blood concentration. It will be shown later that this actually occurs.

From the toxicity figures in Chapter II it may be seen that phosgene in concentrations of 70–80 parts per million may be accepted as the lethal concentration.

The Time Element in Bleeding.

The experience has been gained in phosgene poisoning that acute symptoms do not appear so rapidly as they occur with chlorine. It, therefore, became a matter of particular importance to determine whether early bleeding or later bleeding is more beneficial in the treatment of phosgene poisoning. To test this point bleeding was practiced at a period of one hour in one series of animals and at a period of five hours in a second series, one series comprising 38 animals, the other 30. The results are shown in Table LXXIV.

It is quite evident from these figures that bleeding is decidedly beneficial in phosgene poisoning and that there is very little difference either in acute deaths or ultimate recoveries, of the animals bled one hour or five hours after gassing. One may conclude that it is immaterial whether bleeding is practiced at one or five hours after gassing.

TABLE LXXIV

The Influence of the Element of Time of Bleeding in the Treatment of Phosgene Poisoning

Phosgene concentration 71–80 (0.31–0.35 mgm. per liter)

	Toxicity	*Bled 1% in* *1 hour*	*Bled 1% in* *5 hours*
Percentage of Deaths			
24 hours	36	26	33
2nd Day	19	16	10
3rd Day	9	0	0
Total Acute Deaths	64	42	43
Delayed Deaths	8	8	10
Recoveries	28	50	47
Survivals	36	58	57
Number of Animals	53	38	30

The Influence of Multiple Small Bleedings.

It is possible that repeated small bleedings (20 to 30 cubic centimeters at frequent intervals) would exert equal or greater beneficial effects upon dogs gassed with phosgene than a single large venesection. In Table LXXV the results of such an investigation are recorded for different concentrations of phosgene.

It is quite apparent that multiple small bleedings tend to have a beneficial influence at a concentration 61–70 (0.26–0.30 mgm. per liter) phosgene. The total acute deaths are reduced from 42 per cent to 18 per cent and the recoveries increased from 46 per cent to 63 per cent. Beyond this concentration, however, the favorable effect of this procedure is apparently lost.

TABLE LXXV

The Influence of Multiple Small Bleedings

Concentrations	61–70 (0.26–0.30 mgm.)		71–80 (0.31–0.35 mgm.)		81–90 (0.35–0.39 mgm.)	
	Toxicity	*Bled*	*Toxicity*	*Bled*	*Toxicity*	*Bled*
Percentage of Deaths						
24 hours	17	9	36	35	54	45
2nd Day	25	0	19	15	18	27
3rd Day	0	9	9	12	2	9
Total Acute Deaths	42	18	64	62	70	82
Delayed Deaths	12	9	8	0	9	0
Recoveries	46	63	28	38	21	18
Survivals	58	72	36	38	30	18
Number of Dogs	24	11	38	26	56	11

The Effect of Early Infusion With and Without Previous Venesection.

Although convinced that early infusion was not directly indicated, tests of its influence were made first by infusion of isotonic salt solution alone one hour after gassing and in a second series of animals venesection one hour after gassing followed immediately by infusion of salt solution. In both experiments salt solution to approximately 1 per cent of the body weight was introduced (see Table LXXVI). These data demonstrate that infusion of 0.97 per cent sodium chloride solution to the extent of 1 per cent of the body weight one hour after gassing is distinctly detrimental in phosgene poisoning. It is also quite evident that the results are not as good as those obtained with bleeding only after one hour. The conclusion may be drawn, therefore, that immediate infusion is detrimental under the experimental conditions.

TABLE LXXVI

Influence of Early Infusion

Concentration Phosgene 71–80 (0.31–0.35 mgm. per liter)

	Toxicity	*Infused 1% 0.97% NaCl in 1 hour*	*Bled only*	*Bled in 1 hour and infused 1% 0.97% NaCl*
Percentage of Deaths				
24 hours	36	53	26	40
2nd Day	19	18	16	7
3rd Day	9	0	0	3
Total Acute Deaths	64	71	42	50
Delayed Deaths	8	0	8	7
Recoveries	28	29	50	43
Survivals	36	29	58	50
Number of Dogs	53	17	38	30

Early Bleeding and Delayed Infusion.

When venesection is practiced one hour after exposure to phosgene and infusion of salt solution is made at a period when blood concentration is occurring rapidly results are obtained as recorded in Table LXXVII. Of these 35 dogs only 30 received infusion inasmuch as five animals died previous to the time when it was possible to introduce the salt solution. It is, therefore, quite evident that the figures do not adequately express the influence of the procedure. If only those animals receiving infusion are included then the total recoveries are significantly increased and the animals living beyond the three-day period are increased from 58 per cent with bleeding alone to 80 per cent with bleeding plus delayed infusion. Even without consideration of these five dogs, delayed infusion after early bleeding noticeably reduces acute death even though ultimate recoveries are not increased over bleeding alone.

TABLE LXXVII

Influence of Early Bleeding and Delayed Infusion

Concentration Phosgene 70–80 (0.31–0.35 mgm. per liter)

	Toxicity	*Bleeding only*	*Bleeding and Delayed Infusion*
Percentage of Deaths			
24 hours	36	26	14
2nd Day	19	16	14
3rd Day	9	0	3
Total Acute Deaths	64	42	31
Delayed Deaths	8	8	20
Recoveries	28	50	49
Survivals	36	58	69
Number of Dogs	53	38	35

Experience with Higher Concentrations.

In order to put the methods of treatment to an even greater test observations were made on dogs gassed at a concentration of 80–90 parts phosgene (0.35–0.39 mgm. per liter) per million of air. The results are presented in Table LXXVIII. In these experiments the animal was bled 1 per cent of its body weight one hour after gassing and then, if

TABLE LXXVIII

Influence of Various Types of Treatment

Concentration of Phosgene 80–90 (0.35–0.39 mgm. per liter)

	(1) *Toxicity*	(2) *Single Bleeding*	(3) *Infused Immediately*	(4) *Multiple Infusion*	(5) *Delayed Infusion*	(6) *Exact Treatment*	(7) *Less Exact Treatment*	(8) *Infused 1.0% NaCl according to Hemoglobin*
Percentage of Deaths								
1st Day	54	43	70	54	38	30	44	91
2nd Day	14	13	10	31	20		2	
3rd Day	2	7	10		3		2	
Total Acute Deaths	70	63	90	85	61	30	48	91
Delayed Deaths	9	7		15	6	7	4	9
Recoveries	21	30	10		33	63	48	
Survivals	30	37	10	15	39	70	52	9
Number of Dogs	56	30	20	13	36	30	48	11

it seemed desirable, bleeding to the extent of one-half of 1 per cent was later practiced. Water was given freely. It will be seen that at this concentration a single large bleeding does not yield results much better than the toxicity figures. Bleeding followed by immediate infusion is distinctly detrimental as are multiple infusions. Bleeding plus delayed infusion when *emphasis is placed upon a definite time after gassing for infusion rather than an exact adherence to the degree of concentration of the blood* gives the results seen in Column 5. These are little better than bleeding alone. This observation is a clear indication that in order to yield the best results definite criteria of the animals' condition must be followed closely and the *kind* and *time* of treatment should be practiced in strict accord with these criteria. When changes in temperature and hemoglobin are employed in this connection and treatment is given to dogs gassed with phosgene at a concentration of 80–90 (0.35–0.39 mgm. per liter) parts per million of air, results such as presented in Column 6 are obtained. Obviously, these observations lead to the conclusion that the method of treatment herein outlined is rendered decidedly efficacious when careful consideration is given to the *time* element with respect to infusion. In these results in certain instances more than one infusion was given at times, the number being determined entirely by the response of the change in hemoglobin. If after a single infusion the blood concentration again rapidly increased a second or even a third infusion was given. Column 7 in Table LXXVIII shows that even when the blood concentration and temperature are not followed so closely excellent results may be obtained by following the method in general. One reason for the poorer results shown in Column 7 of Table LXXVIII is that in a number of animals included the wrong strength of salt solution was employed, every animal receiving it dying.

In this connection attention should be called to the necessity of infusion of the correct strength of sodium chloride solution. Our experience has been that excellent results are yielded when this salt solution varies in strength from 0.95 per cent to 0.98 per cent. Variations on either side of these limits are attended with detrimental effects. Thus in Table LXXVIII, Column 8, it may be seen that when dogs were infused with sodium chloride solution of a strength of 1.02 per cent all died even though in every other respect the treatment given was in strict accord with the prescribed method.

Modified Method of Treatment.

The final step in the method of treatment was the recognition that it was unnecessary to infuse every animal exposed to phosgene, and further that by early repeated bleeding the number of gassed animals needing infusion could be appreciably reduced. Moreover, the possibility was presented that inasmuch as the essential feature of infusion is to dilute the blood, even though only temporarily, the same result could be obtained by introducing water by routes other than by direct infusion, namely, by the mouth or intraperitoneally.

The following considerations are pertinent with respect to the modified procedure.

The changes in hemoglobin of the blood and the temperature curve may be accepted as accurate criteria of the condition of the gassed dog.

These criteria may be depended on as indicators of the time for treatment and the *type* of treatment.

Intensive treatment in the first stage (that is, during the period of blood dilution) of phosgene poisoning will, in the majority of cases, prevent extreme concentration of the blood characteristic of the second stage. In other words, the second stage is very greatly modified by proper treatment of the first stage. During the first stage water should not be given.

Proper treatment of the first stage consists in venesection to the extent of 0.5 per cent body weight as soon as practicable after gassing. The temperature and hemoglobin are then followed at one-half hour intervals. So long as the temperature remains normal and blood concentration does not diminish, further treatment is not indicated When, however, the temperature rises rapidly and a fall in blood concentration occurs (the two changes take place simultaneously) a second venesection of 0.5 per cent body weight is practiced. This procedure may be repeated for the second time, that is, until blood to the extent of 1.5 per cent of the body weight has been withdrawn.

The large majority of cases need no further treatment and practically every animal survives.

If in spite of intensive treatment in the first stage the blood becomes markedly concentrated and a marked fall in temperature takes place the condition of the animal must be considered as very serious and if left untreated it will surely die.

Under these conditions two types of treatment have been carried through: (a) to those animals that will drink, large quantities of water are given, or water is given by a sound; (b) infusion or intraperitoneal injection of 0.95 per cent sodium chloride solution is practiced.

Probably 50 per cent of animals in a serious condition in the second stage may be saved by following either procedure.

Injudicious infusion of salt solution may be markedly detrimental, hastening the onset of death. Judicious infusion of salt solution will result in the survival of a large number of animals.

Infusion of salt solution is necessary only with the most serious cases and a considerable degree of judgment should be employed.

Finally, the aim of treatment in phosgene poisoning should be to consider each case as an entity and give treatment only in accordance with changes in temperature and hemoglobin, the criteria of changes in the gassed animal's condition.

In Table LXXIX may be found the observations made with the *modified* treatment and it may be concluded that (1) the results yielded are almost as good as the best ob-

TABLE LXXIX

Modified Treatment

Concentration of Phosgene 81–90 (0.35–0.39 mgm. per liter)

	Toxicity	*Water by Mouth*	*Intraperitoneal Infusion*
Percentage of Deaths			
24 hours	54	47	37
2nd Day	14		12
3rd Day	2		
Total Acute Deaths	70	47	49
Delayed Deaths	9		
Recoveries	21	53	51
Survivals	30	53	51
Number of Dogs	56	15	33

tained when every animal was infused and (2) the modified method is more practical under field conditions than would be a method where intravenous injection is necessary. From a practical viewpoint, then, this modification is of considerable importance. According to our conception equally important, practically, is the fact that not every animal needs even water introduction, the blood concentration being controlled in large measure by the early repeated bleeding. It is significant that by following the modified method delayed deaths are entirely eliminated.

Influence of Water Intake of Animal upon Phosgene Treatment.

It was deemed desirable to determine what influence upon phosgene treatment would be exerted by changing the water intake of an animal previous to gassing. The results may be seen in Table LXXX. If water is withheld from a dog 48 hours previous to exposure to phosgene, response to treatment is very poor. In other words, water starvation previous to gassing exerts a distinctly detrimental effect. The administration of water just previous to exposure to gas gives results entirely comparable with those of the toxicity figures. In other words, too much water is also definitely detrimental. When water administration constitutes the only treatment little or no improvement over the toxicity figures is observed.

TABLE LXXX

Influence of Water Intake upon Treatment

Concentration of Phosgene 80–90 (0.35–0.39 mgm. per liter)

	Toxicity	*48 hours Water starvation*	*Water just previous to Gassing*	*Water administration only treatment*
Percentage of Deaths				
24 hours	54	40	38	44
2nd Day	14	40	19	22
3rd Day	2	7	6	
Total Acute Deaths	70	87	63	66
Delayed Deaths	9		6	6
Recoveries	21	13	31	28
Survivals	30	13	37	34
Number of Dogs	56	15	15	18

Does Infusion of Salt Solution Aggravate Edema?

In certain quarters objection has been raised to the injection of salt solution on the ground that such infusion would tend to aggravate edema and hence, perhaps, exert a detrimental influence. From experiments carried through by Captain Goldschmidt and Captain Wilson, at Porton, England, with goats, it may be stated that this objection is without foundation. Goats gassed with phosgene, bled and infused with sodium chloride solution, give no evidence that this procedure aggravates the existing edema. These results were obtained by determination of the lung to heart (L:H) ratio with and without infusion and if edema were actually increased by the infusion the change would surely be indicated by alterations in this ratio. The results follow:

	Untreated	*Treated*
Number of goats dying after time of treatment	17.	18.
Average length of life of animals that died (days)	2.2	2.3
Average L:H ratios of animals that died	8.6	7.8
Number of animals surviving the acute period	13.	13.
Average L:H ratios of animals surviving the acute period	4.4	3.8

The average L:H ratios are slightly less in the animals that had been treated both in the groups that died and in those which survived. Goats dying after being treated by venesection alone fail to show any marked difference in the L:H ratios. Therefore, the conclusion may be drawn that infusion does not increase the edema of the lungs in phosgene poisoning. Indeed, the evidence indicates that the edema is somewhat decreased.

CHAPTER XIV

THE TREATMENT OF CHLORPICRIN POISONING

The treatment of chlorpicrin poisoning was carried through upon both dogs and goats. In the latter instance the observations were made at Porton,* England, by Captain Goldschmidt and Captain Wilson.

Experiments with Goats.

The method of gassing may be outlined briefly. Ten or twelve goats were placed in the gassing chamber and left for a period of 25 minutes in an atmosphere of chlorpicrin, made by spraying in the liquid in quantities sufficient to develop a theoretical concentration of from one part of chlorpicrin in 8500 to 9000 parts of air. The air in the chamber was kept continually in motion during the period of the gassing by means of an electric fan.

The animals were arbitrarily divided into two equal groups: one group was treated, while the other served as a control. An effort was made to have, so far as possible, an equal division of animals as regards weight and sex, in the two groups. This division was made without any reference to the animal before the gassing was completed, and adhered to regardless of the condition of the respective animals after the gassing.

Bleeding was performed by aspiration through a needle inserted through the skin into the right or left jugular vein. This procedure was performed so far as practicable under aseptic precautions.

One bleeding only was made one hour after the animals were removed from the chamber.

All of the animals which survived were kept under careful observation for a period of 5 to 7 days, and then sacrificed for post-mortem examination. As nearly 90 per cent of the mortalities occurred within the first 24 hours, and most of the surviving animals improved rapidly thereafter, the length of the period of observation is considered ample. Hence it may be safely stated that life or death has been the criterion of the beneficial effect of the treatment employed.

A large number of experiments were performed, but, for present purposes, only those groups in which from 60 to 100 per cent of the goats in the control group died, are selected. Tables LXXXI and LXXXII give the results of these experiments.

As may be seen in Table LXXXI the mortality of the treated animals is decreased from 90 to 57 per cent by a single bleeding in a severely gassed goat. This large reduction in mortality in the 95 animals used in these experiments demonstrates conclusively that bleeding is an efficacious therapeutic procedure when applied early to goats gassed with high concentrations of chlorpicrin. These data have been subjected to statistical analysis and found to be conclusive.

*We are greatly indebted to Lieut.-Colonel Crossley and Mr. Joseph Barcroft for placing these facilities at our disposal, as well as for many helpful suggestions and criticisms.

Table LXXXII shows the percentage deaths (expressed as per cent of animals surviving at the beginning of each period) of experimental and control animals at four periods after gassing. The first critical period occurs within 8 hours after gassing. An inspection of Table LXXXII shows that whereas 40 per cent of the control animals had died at this time, but 17 per cent of the treated animals had succumbed at this period.

The next and more critical period lies between 8 and 24 hours. Here also a greater percentage of the untreated animals die. Hence, a single treatment has furnished protection for the treated animals through the severest of the acute stage of the gassing. After 24 hours the number of treated animals which die is very small; on the other hand, the untreated continue to give an appreciable percentage of deaths. It may, therefore, be concluded that the treatment has given a permanent advantage, and has not merely delayed the death of the animal.

TABLE LXXXI

Effect of Bleeding in Goats Gassed with Chlorpicrin

(1:8500–1:9000 for 25 minutes)

	Animals Used	*Deaths*	*Percentage Deaths*
Untreated	48	43	90
Treated	47	27	57

TABLE LXXXII

Effect of Bleeding upon Goats Gassed with Chlorpicrin

(1:8500–1:9000 for 25 minutes)

Animals grouped according to time of death.

	3–8 hours	*8–24 hours*	*24–28 hours*	*2–7 days*	*Total Deaths*	*Survivals*
Untreated	19	18	2	4	43	5
Treated	8	16	1	2	27	20

Animals surviving at beginning of period:—

Untreated	48	29	11	9
Treated	47	39	23	22

Percentage deaths among animals surviving at beginning of period:—

Untreated	40	62	18	44
Treated	17	41	4	9

Unfortunately, the observations upon goats were not sufficiently extended to show the influence of infusion upon this animal.

Experiments with Dogs.

The first type of treatment which was tried with dogs subjected to chlorpicrin poisoning was multiple bleeding. In Series I (see Table LXXXIII) of this treatment 21 dogs were treated which had been gassed at a concentration of 0.81–0.95 mgm. per liter, and in Series V, 41 dogs which had been gassed at a concentration of 0.96–1.10 mgm. per liter. The animals, as soon as received from the gassing chamber, generally about a half hour after the close of gassing, were bled 1½ per cent of body weight. The animals were followed every hour for hemoglobin. If the hemoglobin showed a concentration the animal was bled another 1½ per cent of body weight and further concentration was followed by further bleeding.

As shown in Table LXXXIII the results obtained from this type of treatment at both concentrations are practically identical with the regular toxicity figures, and it appears clear, considering the large number of animals used, that this type of treatment is of no benefit.

The fundamental idea of this treatment is that if the animals are bled as the blood concentrates, additional fluid will be supplied from the tissues, and as a result the blood will become less concentrated. So far as one can tell this does not happen. The records, in general, give no evidence that the multiple bleedings bring down the concentration of the blood, and in fact, in some cases at least, it continues to increase more rapidly than without bleeding. It appears probable that as soon as the edema begins to develop in the lungs, with a consequent loss of fluid from the blood, the tissues are immediately called upon to supply additional fluid. As long as fluid is supplied from the tissues in this manner, the concentration of the blood will be kept to a minimal figure, but as soon as the fluid reserve of the tissues is exhausted, the concentration of the blood will increase in exact ratio to the development of edema in the lungs. Inasmuch, then, as the fluid reserve of the tissues has been used by this time, it appears logical to suppose that additional bleeding would only further aggravate the concentration and this is apparently what happens.

In Series II the animals were not bled, but given 2 per cent of body weight of water by stomach tube within an hour after gassing. The treatment of this series was just the opposite of that in Series I. To counteract the concentration of the blood, fluid is supplied at once which can be absorbed into the blood stream, and the blood thus kept at a lower concentration. The recoveries by this treatment are only very slightly above the toxicity figures.

In Series IV and VII, the final treatment adopted, the animals were bled 1½ per cent of body weight within a half hour after the close of gassing and 2 per cent water was given to the animal at once by stomach tube. The animals were closely followed and in case a need of further fluid was indicated by hemoglobin or temperature, it was supplied. Fifteen animals were treated by this method which had been gassed at a concentration of from 0.81–0.95 mgm. per liter, and (Series VII) 9 animals which had been gassed at a concentration between 0.96–1.10 mgm. per liter. Out of the 15 animals at the lower concentration, there were no deaths the first day and only three deaths altogether, giving a percentage of recoveries of 80 per cent. At the higher concentration there were two deaths the first day and one the second day, leaving 6 animals which recovered, or prac-

TABLE LXXXIII

CHLORPICRIN TREATMENT

Concentration of chlorpicrin 111–131 (0.81–0.95 mgm. per liter)

		Series I		*II*		*III*		*IV*	
		No. Dogs		*No. Dogs*		*No. Dogs*		*No. Dogs*	
	Toxicity	*21*	*Per cent*	*11*	*Per cent*	*9*	*Per cent*	*15*	*Per cent*
Percentage of Deaths									
1st Day	30	9	43	6	54	2	22	0	0
2nd Day	17	1	5	0	0	2	22	2	13
3rd Day	6	0	0	0	0	0	0	1	7
Total Deaths in 3 Days	53	10	48	6	54	4	44	3	20
Survivals	47	11	52	5	46	5	56	12	80
Delayed Deaths	4	1	5	0	0	0	0	0	0
Recoveries	43	10	47	5	46	5	56	12	80

Concentration of chlorpicrin 132–151 (0.96–1.10 mgm. per liter)

		Series V		*VI*		*VII*	
		No. Dogs		*No. Dogs*		*No. Dogs*	
	Toxicity	*41*	*Per cent*	*9*	*Per cent*	*9*	*Per cent*
Percentage of Deaths							
1st Day	55	27	66	4	45	2	22
2nd Day	8	0	0	1	11	1	11
3rd Day	2	1	2	0	0	0	0
Total Deaths in 3 Days	65	28	68	5	56	3	33
Survivals	35	13	32	4	44	6	67
Delayed Deaths	2	0	0	0	0	0	0
Recoveries	33	13	32	4	44	6	67

Description of Treatment Used.

Series I—Multiple bleeding. Animals bled 1/2 per cent of body weight within 1/2 hour after close of gassing. Further bleedings of same amount upon concentration of blood.

Series II—No bleeding. Animals given 2 per cent of body weight of H_2O by stomach tube within 1/2 hour after close of gassing. Further fluid supplied according to hemoglobin and clinical symptoms.

Series III—Bled 1 per cent of body weight within 1/2 hour after gassing and 2 per cent H_2O by stomach tube immediately after bleeding. Additional fluid supplied by intravenous or intraperitoneal infusion of isotonic saline if indicated by hemoglobin or clinical symptoms.

Series IV—Same as Series III except animals were bled 1/2 per cent of body weight instead of 1 per cent.

Series V—Same as Series I.

Series VI—Bled 1 per cent and intravenous infusion of 1 per cent isotonic saline within two hours after close of gassing.

Series VII—Same as Series IV.

tically 67 per cent. The percentage survivals in this treatment series is very much greater than in the regular toxicity groups.

This same treatment was tried, with the exception that the animals were bled 1 per cent of body weight instead of $\frac{1}{2}$ per cent. As shown in Series III, 9 animals were thus treated, of which 5 recovered, giving a percentage recovery of about 56 per cent, as compared with 80 per cent when the $\frac{1}{2}$ per cent bleeding was used. Although the number of animals used in this series was small, the results clearly indicated that the $\frac{1}{2}$ per cent bleeding was the better.

In Series VI 9 dogs, which had been gassed at a concentration of 0.96–1.10 mgm. per liter, were bled 1 per cent of body weight and given an intravenous infusion of 1 per cent of body weight of normal saline immediately afterwards, the whole process taking place within 2 hours after gassing and at the time when blood began to concentrate. The percentage of survivals for this was 44 per cent, which is an increase of 12 per cent over regular toxicity recoveries, and is a decrease of 23 per cent when compared with the final adopted treatment as given in Series VII.

The final treatment, as given above in Series IV and VII, appears to be a logical one when the condition of a gassed animal is considered. The bleeding of $\frac{1}{2}$ per cent of body weight is not sufficient to weaken the animal in any way, but *a priori* would appear to be efficacious in two ways. In the first place, providing any toxic substances had been taken up by the blood, as a result of gassing, the bleeding serves to relieve the blood of a certain amount of these substances. In the second place, the bleeding initiates influx of new fluid from the tissues into the blood. As the edema in the lungs develops and the blood concentrates, the influx continues until the fluid reserve of the tissues, augmented by the 2 per cent of body weight of water given at the time of bleeding, has been depleted, or, in the less serious cases, until the edema of the lungs has ceased to develop.

In the animals which are seriously affected this basic treatment of bleeding and supplying of fluid by mouth or intraperitoneally is not sufficient to save the animals. Evidently, in such cases the edema of the lungs continues to develop so rapidly that even the augmented fluid reserve becomes exhausted. In serious cases of this type it has been found that an intravenous injection of about 1 per cent of body weight of normal saline will, at once in many cases, reduce the concentration of the blood to such an extent that the animal will be carried through the period of rapid edema development. Such an infusion can be repeated if necessary.

It is quite obvious from the data that the most efficacious method of treatment in chlorpicrin poisoning is to bleed $\frac{1}{2}$ per cent of the body weight as soon as possible after gassing and then at once administer water by way of the mouth. Additional fluid may be supplied later by intravenous infusion of sodium chloride solution in accord with hemoglobin readings and temperature changes. With this treatment there are no "delayed deaths."

CHAPTER XV

OXYGEN IN THE TREATMENT OF GAS POISONING

Clinical experience in gas poisoning leads to the conclusion that lack of oxygen plays a significant rôle in this condition. This inference has been confirmed by experimental evidence already discussed in a previous chapter (Chapter IX) and various possibilities may be cited as causes for the establishment of anoxaemia. Thus it is possible that the inflammatory changes in the lungs may hinder the absorption of oxygen. Vascular obstruction in the lungs owing to swelling of the alveolar tissues, and the development of edema may also result in poor oxygen absorption, or, again, there may be an irregular distribution of air in the lungs owing to shallow breathing or partial obstruction of some of the bronchi. Any one or all of these conditions may operate to decrease oxygen absorption. All of these possibilities, however, carry with them the assumption that there is an *inadequate oxygenation of the blood*, meaning thereby an insufficient supply of oxygen in the arterial blood. According to the experimental results previously recorded there is little or no evidence of an inadequate supply of oxygen in the arterial blood during the first part, if not the whole, of the first period of phosgene poisoning. When, however, blood concentration becomes marked, insufficient oxygen in the arterial blood is quite apparent. In a previous chapter emphasis has been laid upon changes in blood concentration as the responsible factor leading to the condition of anoxaemia. According to this view the viscosity of the concentrated blood leads to impaired circulation through the tissue capillaries, thus accounting for the abnormally low oxygen content of the venous blood. Oxygen lack in the arterial blood is not present to the same degree.

From these observations it becomes apparent that the need for oxygen in the first period of phosgene poisoning is not great. In the second period, however, oxygen lack becomes quite pronounced, especially in the venous blood. The question naturally arises, "Will administration of oxygen eliminate anoxaemia?" Again, if anoxaemia is alleviated will this allow an individual to survive the effects of phosgene poisoning? In other words, is inadequate oxygenation of the blood responsible for death? From clinical experience there seems to be conflicting evidence as to the value of oxygen in the treatment of phosgene poisoning. On the whole, however, it would appear that the consensus of opinion indicates that oxygen administration is decidedly beneficial in the circumstances under discussion.

The Influence of Oxygen Administration upon Phosgene Poisoning.

In order to ascertain whether oxygen administration is of therapeutic value dogs gassed with the lethal concentration of phosgene (70–80 parts per million of air; 0.30–0.35 mgm. per liter) were placed in a respiratory chamber through which oxygen was circulated. The concentration of oxygen selected was 50 per cent, small variations from this figure occurring during the course of the experiments. Analysis of the air in the chamber was made from time to time. The dogs were placed in the chamber 2 to 5 hours after gassing and kept there continuously up to a period of 72 hours. This period was selected for the reason that it was chosen as the limit of the duration of the acute stage of poisoning. Arrangements were made for the absorption of carbon dioxide and regulation of moisture and temperature within the chamber. Water was supplied to the experimental animal. For the details of the method of oxygen administration and a description of the apparatus see Appendix to Chapter XV, page 294.

The investigation was carried out upon 30 dogs to which oxygen was administered. A control series of 27 animals gassed at the same concentration, but without any treatment, except that they were kept quiet and warm in the same room with the experimental dogs, was also observed (see Table LXXXIV).

TABLE LXXXIV

The Influence of Oxygen Administration upon the Mortality of Dogs Gassed with Phosgene

	Oxygen Series		*Control Series (no oxygen)*	
	No. of Dogs	*Per cent*	*No. of Dogs*	*Per cent*
Deaths in				
24 hours	17	57	17	63
2 days	2	6	3	11
3 days	0	0	0	0
Total Acute Deaths	19	63	20	74
Delayed Deaths	2	20	1	14
Recoveries	9	27	6	22
Survivals	11	47	7	36
Number of Dogs	30		27	

The results indicate, under the experimental conditions, that:

1. In both series by far the larger percentage of deaths occur within the first 24 hours.
2. All the animals that die (exclusive of "delayed deaths") do so within 48 hours.
3. Oxygen increases but slightly the percentage of survivals, from 26 per cent to 37 per cent.
4. Oxygen has even less effect on prolonging the life of the dogs beyond the first 24 hours.
5. Oxygen does not increase the number of dogs that survive the "acute period" to die later of secondary causes.
6. Oxygen does not markedly increase the percentage of dogs that ultimately recover.

If instead of employing the exact controls comparison is made between the so-called "toxicity figures" as given in Chapter II, page 9, and the results obtained with oxygen administration, the beneficial influence of oxygen upon dogs gassed with lethal concentrations of phosgene is entirely lacking. The results especially with respect to the survivals beyond the acute period and the ultimate recoveries are almost identical (Table LXXXV).

Although these figures are very striking too much emphasis should not be laid upon them, inasmuch as the numbers of animals employed in the two series are too dissimilar. This comparison, however, emphasizes the fact, revealed by the comparison with the actual control series, that continuous oxygen administration after phosgene poisoning does not appreciably decrease the percentage of deaths nor can it be said to materially prolong life. There is the same difference present that may be obtained when two series of animals are gassed by different observers under unlike environmental conditions. Though this conclusion is inevitable from the data it must be conceded that oxygen administration seems to relieve the animal. It rests more quietly, respiration is less difficult and obvious cyanosis disappears or is absent. From the failure of oxygen to prolong life in spite of obvious improvement in clinical symptoms it would appear that such a therapeutic measure does not alleviate the fundamental difficulty in phosgene poisoning.

TABLE LXXXV

COMPARISON OF TOXICITY FIGURES FOR PHOSGENE AND THOSE OBTAINED BY OXYGEN ADMINISTRATION

Concentration of Phosgene 71–80 (0.31–0.35 mgm. per liter)

	Toxicity Figures per cent	*Oxygen Figures per cent*
Deaths in		
24 hours	36	57
2 days	19	6
3 days	9	0
Total Acute Deaths	64	63
Delayed Deaths	8	10
Recoveries	28	27
Survivals	36	37
Number of Dogs	53	30

The Influence of Oxygen Administration upon the Mortality of Gassed Dogs Treated by Venesection.

A series of 30 dogs was gassed with a lethal concentration of phosgene (71–80 parts per million or 0.31–0.35 mgm. per liter of air) and one hour later 1 per cent of the body weight of blood was withdrawn from the jugular vein or from the femoral artery, in both cases without anesthesia. The animals were then placed in the oxygen chamber and kept there up to 72 hours The results of these observations may be seen in Table LXXXVI, where a comparison is made with the effects of bleeding alone. It is quite obvious from these results that bleeding plus oxygen administration as a therapeutic measure has no appreciable advantage over simple venesection. Although carried through by different men in separate laboratories at different times of the year, the results in the two series of observations have a striking similarity, both of kind and degree.

TABLE LXXXVI

The Influence of Oxygen upon Gassed Dogs Treated by Venesection

	With Oxygen		*Without Oxygen*
	No. of Dogs	*Per cent*	*Per cent*
Deaths in			
24 hours	6	20	26
2 days	4	13	16
3 days	4	13	0
Total Acute Deaths	14	46	42
Delayed Deaths	1	6	8
Recoveries	15	50	50
Survivals	16	56	58
Number of Dogs	30		38

The Influence of Oxygen Administration upon the Mortality of Dogs Gassed with a Sublethal Concentration of Phosgene.

A series of 14 dogs gassed at a concentration of 50–60 parts of phosgene per million parts of air (0.21–0.26 mgm. per liter) for ½ hour was also treated with oxygen. The results obtained show that 57 per cent of the dogs survived beyond the three-day period. The toxicity figure is 54 per cent. Oxygen can be said, therefore, to have no beneficial effect on dogs gassed at a concentration lower than "lethal." This is corroborated when the recoveries in the two cases are compared—43 per cent with treatment as against 44 per cent without treatment (Table LXXXVII).

TABLE LXXXVII

Influence of Oxygen upon Dogs Gassed with Sublethal Concentrations of Phosgene and Treated by Venesection

	With Oxygen per cent	*Without Oxygen per cent*
Deaths in		
24 hours	14	26
2 days	0	13
3 days	29	8
Total Acute Deaths	43	47
Delayed Deaths	14	10
Recoveries	43	44
Survivals	57	54
Number of Dogs	14	39

The next logical step would have been to discover the influence of oxygen administration upon the final prescribed treatment for phosgene poisoning, namely, venesection followed by infusion of sodium chloride solution.

Just before it was imperative to discontinue the work a series of experiments was started in this direction from which results of a positive nature were anticipated. In this series the dogs were bled 1 per cent of their body weight, as soon after gassing as possible, followed at the proper time by an infusion of warm, sterile, isotonic (0.95 per cent) NaCl, and the dogs then placed in the oxygen apparatus. When the outcome of the work dealing with the study of the blood oxygen after gassing, the dog breathing air as compared with breathing oxygen, before and after bleeding, and before and after infusion, is read (see page 177), it will be realized why the carrying out of this series seemed to be so promising of results. The particular point involved is the ability of the gassed dog to get hold, as it were, of the additional amount of oxygen provided, as well as of that in atmospheric air, as evidenced by the arterial and venous oxygen content when infusion is carried out. Three dogs only were thus treated. The first died just under 72 hours after gassing, the other two recovered.

Observations on the Administration of Oxygen to Dogs Gassed with Chlorine.

The administration of oxygen to chlorine dogs placed in the circulating apparatus was substantially the same as that used for phosgene, except that since the work on chlorine was done first, the apparatus was not as complete as it was later.

Three dogs were given oxygen, with no previous treatment, after gassing. Of these none survived. The first died on the second day; the other two on the first day.

Eight dogs were given oxygen after treatment as developed at the time. Within ½ hour after gassing the dogs were bled 1 per cent of their body weight by aspiration from the jugular vein. The same amount of warm, sterile, isotonic (0.95 per cent) NaCl was then slowly infused, after which 50 cubic centimeters of 10 per cent $NaHCO_3$ were given by a stomach tube. The dog was then placed in the oxygen box, and the concentration of oxygen in the circulating air gradually raised to approximately 50 per cent in the manner described in the report of the work on phosgene. The outcome of this experiment is recorded in Table LXXXVIII.

At this concentration of chlorine the toxicity series shows a percentage recovery of 9 per cent. The number of dogs involved in the present series is entirely too small to warrant a definite conclusion. The fact that the percentage of recoveries is increased by 16 per cent may be of significance. On the other hand, when comparison is made with treatment figures obtained, it is true, in a large number of dogs, it would appear that oxygen has little influence in increasing the number of recoveries, that is, with oxygen the recoveries were 25 per cent, without oxygen 29 per cent.

The Determination of Oxygen Changes in the Blood of Gassed Dogs Breathing Air in Comparison with Breathing Oxygen.

After it had been shown that oxygen administration alone or in combination with venesection is of doubtful value in reducing the mortality of dogs gassed with phosgene, it was deemed important to determine the exact changes that occur in the respiratory functions of the blood after exposure of animals to phosgene. Therefore, the oxygen of the blood has been determined in gassed dogs breathing air and breathing oxygen. As an ideal procedure for this purpose blood should be drawn from the right and left ventricles for the samples of venous and arterial blood respectively, inasmuch as the blood contained in these receptacles undoubtedly more nearly represents the average composition than blood secured at a greater distance from the heart.

TABLE LXXXVIII

The Influence of Oxygen upon Dogs Gassed with Chlorine
Treated by the Standard Method

	Treatment With Oxygen		*Treatment Without Oxygen*
	No. of Dogs	*Per cent*	*Per cent*
Deaths in			
24 hours	3	37.5	43
2 days	3	37.5	3
3 days	0	0	0
Total Acute Deaths	6	75	46
Delayed Deaths	0	0	25
Recoveries	2	25	29
Survivals	2	25	54
Number of Dogs	8		28

Although the figures may not be identical, the general results obtained by analysis of heart blood and that of vein and artery blood are of the same kind. This has been demonstrated. In the present investigation the venous blood was obtained by aspiration through a needle inserted through the skin into a jugular or femoral vein, and the blood drawn into a test tube under albolene. The arterial blood was obtained in the same way through a needle inserted through the skin into a femoral artery, the position of the artery being determined by palpation.

Experiments with Normal Animals.

It was first ascertained whether the oxygen content of the arterial and venous blood of the normal dog can be raised by the administration of oxygen. As a result of these experiments (see Table LXXXIX) it is quite evident that this is possible in those cases in which the arterial percentage saturation was low originally. It is not, however, an invariable rule.

It should be noted that, in the cases where the percentage saturation of the venous blood shows a decrease while the dog is breathing oxygen as compared with the value obtained when the animal was breathing air, the contents do not vary by much more than 1.5 per cent. This is the error of the method used for analyzing oxygen (Henderson-Smith method).

TABLE LXXXIX

THE ARTERIAL AND VENOUS OXYGEN CONTENT AND PERCENTAGE SATURATION BREATHING AIR AS COMPARED WITH BREATHING OXYGEN (APPROXIMATELY 50 PER CENT). THE CAPACITY OF THE BLOOD (OXYGEN-COMBINING POWER) IS ALSO GIVEN.

NORMAL DOGS

		BREATHING AIR				BREATHING OXYGEN			
No.	*Capacity*	*Arterial Content*	*Venous Content*	*Arterial percentage Saturation*	*Venous percentage Saturation*	*Arterial Content*	*Venous Content*	*Arterial percentage Saturation*	*Venous percentage Saturation*
88	21.9	19.4	9.8	88	44.8	19.1	7.8	87.2	35.6
89	16.2	14.8	10.2	91	62.9	14.9	11.6	92.0	71.6
92	24.9	20.2	17.8	81	71.5(?)	21.9	15.5	88.0	62.2
99	15.9	16.0	9.4	100	59.8	15.8	8.2	99.4	51.5
101	17.7	15.8	9.2	89	52(?)	15.6	13.9	88.2	78.5(?)
102	18.0	16.4	11.5	91	63.8	16.4	11.4	91.2	63.4
103	15.7	12.4		80*		14.3		91.1*	
104	18.6	17.3	9.3	93	50.0	18.4	13.3	98.0	72.0

*Died soon after gassing.

Experiments with Gassed Animals.

The study of the blood oxygen was undertaken primarily to discover whether the determination of its content in the arterial and venous blood would not indicate the reason why oxygen alone seemed to have no therapeutic value, since, as has been noted above, the percentage of survivals in those series in which oxygen was given was practically identical with that obtained in the "toxicity series," for the same concentration of gas.

A study of Table XC will show that in spite of the administration of oxygen and the ability of the animal to raise the oxygen content of the blood, in general, the percentage saturation became successively lower. In other words, although additional oxygen can in many cases be forced into the blood in relatively great amounts either soon after or several hours after gassing, nevertheless, owing to the gradual decrease of the oxygen content of the blood, and the consequent lowering of the percentage saturation, the blood is farther and farther away from saturation.

TABLE XC (Series 1)

THE INFLUENCE OF OXYGEN ADMINISTRATION UPON THE PERCENTAGE SATURATION AND OXYGEN CONTENT OF THE BLOOD OF DOGS GASSED WITH PHOSGENE

(71–80 parts per million) (0.31–0.35 mgm. per liter)

No.	*Time*	*Capacity*	*Arterial Content*	*Venous Content*	*Arterial Percentage Saturation*	*Venous Percentage Saturation*	*Hemoglobin*	*Remarks*
89	3.00	16.2	14.8	10.2	92.0	62.9	85	Normal, breathing air. 7/17
	4.00	16.2	14.9	11.6	92.0	71.6	80	Normal, breathing oxygen
								Gassed, 8.39 a. m. 7/18
	10.30	15.1	15.4		100.0		85	breathing air
	1.15	16.1	14.9	7.1	92.0	48.0	80	breathing air
	2.30	17.4	16.6		95.0		85	breathing oxygen
	3.30	16.8	16.0	2.5	95.0	15.0	85	breathing oxygen
	4.45	17.7	10.1		57.0		?	breathing air
92	9.45	24.9	20.2	17.3	81.0	71.5		Normal, breathing air. 7/22
	11.00	24.9	21.9	15.5	88.0	62.2	90	Normal, breathing oxygen
								Gassed, 8.37 a. m. 7/23
	1.00	23.3	20.9	14.0	90.0	60.0		breathing air
	4.00	27.5	28.7	20.3	100.0	73.0	140	breathing oxygen
	5.15	28.9	25.3	3.8	87.0	9.9	140	breathing air
95	10.30	18.7	17.4	8.4	93.0	45.0	85	Normal, breathing air. 7/25
								Gassed, 3.47 p. m. 7/25
	9.30	25.0	17.0	8.0	68.0	32.0	100+	breathing air
	11.00	25.0	20.3	9.6	81.0	38.0	110	breathing oxygen
	2.45	25.0	11.6	4.3	46.4	17.0	120	breathing air
	4.00	25.0	14.7		59.0		160	breathing oxygen
101	2.45	17.7	15.8	9.2	89.0	52.0	85	Normal, breathing air. 7/29
	3.45	17.7	15.6	13.9	88.2	78.5	90	Normal, breathing oxygen
								Gassed, 9.20 a. m. 7/30
	10.45	12.8	12.2	4.1	95.0	32.0		breathing air
	1.50	15.2	12.7	4.1	83.0	27.0		breathing air
	3.20	21.6	14.3	4.9	66.0	22.0	120	breathing oxygen
	4.30	24.8	11.3		46.0		130	breathing oxygen (died 5 p. m.)
104	2.50	18.6	17.3	9.3	93.0	50.0	75	Normal, breathing air. 7/31
	4.30	18.6	18.4	13.3	98.0	72.0	75	Normal, breathing oxygen
								Gassed, 9.53 a. m. 8/1
	2.00	18.0	15.4		85.0		65	breathing air
	3.45	21.6	15.0		69.0		90	breathing air
	5.40	21.7	12.3		56.0		56	breathing oxygen (died 5.45 p. m.)

TABLE XC (continued)

No.	*Time*	*Capacity*	*Arterial Content*	*Venous Content*	*Arterial Percentage Saturation*	*Venous Percentage Saturation*	*Hemoglobin*	*Remarks*
105	2.30	24.4	22.4	14.9	91.0	61.0	95	Normal, breathing air. 8/1
								Gassed, 4.20 p. m. 8/1
	9.30	27.1	25.1	9.4	93.0	34.0	140	breathing air. 8/2
	10.45	27.1	23.6	11.6	87.0	43.0		breathing oxygen
	2.15	24.7	21.5	9.3	87.0	38.0	130	breathing air
	3.35	24.6	24.3	9.7	100.0	39.0	140	breathing oxygen
	4.20	24.6	24.5		100.0			breathing oxygen
	5.15	18.5(?)	10.2	7.4	55.0	40.0	130	breathing air
	10.00	17.7	16.4	2.2	93.0	12.0	95	breathing air. 8/3
	9.00	15.6	14.8	5.1	95.0	32.0	90	breathing air. 8/5
113	10.00	18.1	17.5	10.1	97.0	55.8	85	Normal, breathing air. 8/8
								Gassed, 9.17 a. m. 8/9
	1.00	24.5	22.4	6.6	91.0	27.0	130	breathing air
	3.00	27.0	28.9	2.6	100.0	9.9	140	breathing oxygen
	3.45	30.5	22.7	0.0	74.0	0.0	140	breathing air (died 3.52 p. m.)

The hemoglobin values are only approximate, having been determined by the Talquist scale.

It has often been observed that it is impossible to raise the venous content, although the arterial content may be markedly increased. This would seem to indicate that while there may be an abundance of oxygen in the arterial blood for ordinary purposes, there is such an increased demand for it on the part of the tissues that the increased amount not only does not get to the venous blood, but the oxygen there may show a continued marked decrease. Dog No. 89 is an example of such a case, in which, although the oxygen in the arterial blood was increased, the percentage saturation being raised from 90 per cent to 95 per cent—the capacity showing relatively little change—it was impossible to prevent a very rapid fall in the oxygen content of the venous blood. As long as the dog was breathing oxygen the arterial percentage saturation remained high, but fell off rapidly when atmospheric air was substituted for the 50 per cent oxygen. Dog No. 113 exemplifies a similar condition.

Speaking of the "capacity" is perhaps applying a misnomer for the condition which we have in these gassed dogs. That is, the term does not here represent the true combining power of the blood, in the body, with oxygen, in the conditions where the blood has thickened considerably. A cubic centimeter of thickened blood contains more corpuscles and, therefore, more hemoglobin in ratio to the plasma, than does a cubic centimeter of blood of normal or average viscosity. In the body the capacity of the blood as a whole must be really lower, since it has lost in volume, due to the loss of water. This probably explains, in part, the drop in oxygen content. Furthermore, the increased viscosity slows the blood stream, and leads to poor oxygenation of the tissues.

Dog No. 105, an animal that recovered, illustrates a recovery which is plainly not due to the oxygen. Seventeen hours after gassing the percentage saturation of the arterial blood was practically the same as the normal figure (93 per cent as compared with 91 per cent). The arterial content rose parallel with the capacity, the former increasing from 22.4 to 25.1, the latter from 24.4 to 27.1.

The venous content, on the other hand, had dropped from 61 per cent to 23 per cent. Oddly enough, when the blood was examined after the dog had been breathing oxygen, the arterial content was found to be lower, while the venous content was higher. This is obviously a mistake in the one or the other analysis. But it is interesting to note that the next arterial sample, taken at 2.15, had a lower oxygen content still, although the percentage saturation was the same as the oxygen-breathing sample, due to a gradual fall in the capacity; and that the sample of venous blood when the dog was breathing air had about the same content as a previous sample taken when the dog was breathing air at 9.30. Be that as it may, the next administration of oxygen beginning at 2.20 raised the arterial content to 100 per cent saturation, although the capacity was decreasing all the time, and kept it raised, while the oxygen of the venous blood seems to have been prevented merely from decreasing. There was a sharp falling off of the oxygen in the arterial blood, the saturation dropping to 55 per cent, after the dog was returned to air, and a drop in the capacity, which had the effect of raising the saturation of the venous blood, although the venous content was actually lower. The later figures show the conditions 41 to 65 hours after gassing respectively. The capacity decreased still further, below normal, and at 41 hours after gassing the venous saturation dropped as low as 12 per cent, although the arterial was practically normal (93 per cent). Sixty-five hours after gassing the venous percentage saturation had risen to 32 per cent, or about the value for it 17 hours after gassing, but only about one-half that of normal.

Dog No. 113 shows in summary fashion the inefficiency of oxygen as a therapeutic agent alone, in a crucial case, that is, one in which the effects of the poison are advancing rapidly. This case shows as marked and as rapid a rise in the "capacity," or of the thickening of the blood, as any that have come under our observation. The arterial content rises with the capacity, but not fast enough to keep up the percentage saturation, which has dropped from 97 per cent to 91 per cent four hours after gassing. The venous blood lost oxygen. Oxygen administration was begun at the 5th hour after gassing. The percentage saturation of the arterial blood six hours after gassing was 100 per cent, the venous continued to fall rapidly. Forty-five minutes later, although still breathing oxygen the percentage saturation had fallen to 74 per cent, while there was no oxygen, that could be detected, in the venous blood. The content of the arterial blood at this time was the same as its value four hours after gassing while the dog was breathing air. But the capacity was now 30.5 as compared with 24.5 then. Another sample taken five minutes later, the dog having been returned to air, showed a still further decrease in oxygen content of the arterial blood, and a few minutes later the dog died.

This case is particularly important as illustrating the futility of dealing directly with one of the *secondary* effects of gas poisoning, viz., the reduced amount of oxygen in the tissues. The lack of oxygen must be in one of two places, either in the arterial blood, because it cannot be taken up from the lungs; or, if the arterial blood can take up oxygen in additional amount, the lack of oxygen is in the tissues themselves. The first possibility is ruled out inasmuch as oxygen can be absorbed by the gassed lungs. In spite of the fact that the oxygen of arterial blood may be within normal limits under oxygen administration there still may be evident oxygen want in the tissues. Obviously oxygen administration alone does not eliminate the crucial condition in gas poisoning, namely, lack of oxygen in the tissues. Although an additional amount of oxygen in the inspired air may be of some benefit to the tissues, the primary object in treatment should be to remove or modify the cause for the lack of oxygen.

Although oxygen could not be shown to have a curative effect on dogs gassed at the "lethal" concentration (viz., 70–80 parts of phosgene per million of air; 0.30–0.35 mgm. per liter), the question was raised as to whether it would be beneficial to animals gassed at a lower concentration, and perhaps thus more in accord with conditions of men in the trenches. Accordingly, the study of the oxygen in the blood of dogs gassed at a concentration of 50–60 parts phosgene (0.21–0.26 mgm. per liter) was made. Table XCI is a summary of the results. From these data the same general conclusions may be drawn regarding dogs gassed with a concentration of phosgene lower than lethal as pertained to dogs gassed at 70–80 (0.30–0.35 mgm. per liter). In some cases it is impossible to raise the venous content (No. 126), although this is exceptional. In others, after an initial raising of the percentage saturation of both arterial and venous blood, there is a more or less rapid fall even while the animal is breathing oxygen, which becomes more rapid after a return to breathing air (e. g., Nos. 123 and 134).

TABLE XCI (Series 2)

The Influence of Oxygen Administration upon Percentage Saturation and Oxygen Content of the Blood of Dogs Gassed with Phosgene

(50–60 parts per million) (0.21–0.26 mgm. per liter)

No.	*Time*	*Capacity*	*Arterial Content*	*Venous Content*	*Arterial Percentage Saturation*	*Venous Percentage Saturation*	*Hemoglobin*	*Remarks*
116	11.00	20.8	17.8	12.0	85.0	57.6	90	Normal, breathing air. 8/12
								Gassed, 3.10 p. m. 8/12
	9.00	23.8	20.7	7.3	87.0	30.7	150	breathing air. 8/13
	10.00	23.2	21.3	6.4	92.0	27.6	170	breathing oxygen
	11.00	22.5	19.9	7.4	88.0	32.9	120(?)	breathing oxygen
	2.30	22.5	17.9	5.4	79.0	24.0	130	breathing air
	3.45	22.0	18.4	10.0	83.0	45.4	130	breathing oxygen
	4.30	20.2	16.6	5.9	82.0	29.0	140	breathing oxygen
118	1.15	25.3	23.0	17.6	91.0	69.6	90	Normal, breathing air. 8/12
								Gassed, 2.16 p. m. 8/13
	9.10	29.1	25.4	10.0	87.0	34.3	130	breathing air. 8/14
	10.10	27.6	25.7	15.7(?)	83.0	57.0	140	breathing oxygen
	11.15	27.6	25.5	11.4	83.0	41.3	140	breathing oxygen
	12.00	27.7	7.0	2.9	25.0	10.4	140	breathing air
	3.00	24.8(?)	18.4	3.1	74.0	12.7	140	breathing air
	4.00	27.9	23.4	7.3	84.0	26.1	140	breathing oxygen
	4.15	27.9	10.9		39.0		140	breathing air
121	9.00	10.9	9.5	4.3	87.0	39.7	80	Normal, breathing air. 8/15
	12.00	10.1	9.1	2.9	90.0	28.7	80	Normal, breathing air. 8/15
								Gassed, 8.59 a. m. 8/16
	2.30	14.6	7.5	0.7(?)	51.0	4.7	90	breathing air
	3.35	14.0	10.9	3.0	78.0	21.4	80	breathing oxygen
	4.20	14.8	11.9	1.3	81.0	8.8	80	breathing oxygen
	4.30	14.8	2.9		24.0			breathing air
123	11.30	14.9	13.7	2.5	92.0	17.8	80	Normal, breathing air. 8/16
								Gassed, 3.57 p. m. 8/16
	9.00	18.3	15.4	1.7	84.0	9.3	140	breathing air. 8/17
	9.45	20.3	17.6	2.6	86.0	12.8	150	breathing oxygen
	11.00	20.3	15.2	1.5	74.0	7.4	145	breathing oxygen
	11.30	20.3	6.8	0.0	33.0	0.0	145	breathing air

TABLE XCI (continued)

No.	*Time*	*Capacity*	*Arterial Content*	*Venous Content*	*Arterial Percentage Saturation*	*Venous Percentage Saturation*	*Hemoglobin*	*Remarks*
126	9.15	18.0	16.7	10.0	92.7	55.5	90	Normal, breathing air. 8/19
								Gassed, 2.13 p. m. 8/20
	11.25	24.7	23.8	12.1	96.3	49.0	135	breathing air. 8/21
	12.00	23.4	24.0(?)	10.7	100.0	45.8	135	breathing oxygen
	12.23	24.0	24.2		100.0		135	breathing oxygen
	12.40	24.0	23.7	10.2	99.0	42.0	130	breathing oxygen
	1.05	24.0	21.2		88.0		130	breathing air
	10.15	21.9	19.1	8.4	82.6	38.3	110	breathing air. 8/22
131	11.40	21.6	13.2	12.0	61.1	55.5	120	Normal, breathing air. 8/22
								Gassed, 9.52 a. m. 8/23
	11.45	17.9	17.5	8.0	97.7	44.6	120	breathing air
	2.45	20.7	19.6	8.2	94.8	40.0	120	breathing air
	3.20	20.5	19.2	8.3	93.6	41.2	120	breathing oxygen
	3.45	20.2	21.3	11.7	100.0	57.9	120	breathing oxygen
	4.10	20.5	20.5		100.0		120	breathing oxygen
	4.35	23.3	20.2	13.1(?)	86.7	56.2	120	breathing air
	12.00	23.7	20.4	2.5	86.0	10.5	120	breathing air. 8/24
134	10.30	21.3	20.9	8.4	93.0	39.0	100	Normal, breathing air. 8/26
								Gassed, 11.00 a. m. 8/26
	8.45	27.5	14.6	7.3	53.0	27.0		breathing air. 8/27
	9.20	27.0	23.2	8.0	85.0	29.0	120	breathing oxygen
	9.50	26.4	20.9	12.1	79.0	45.0	140	breathing oxygen
	10.25	26.0	19.9	10.7	76.0	41.0	140	breathing oxygen
	11.30	25.3	13.6	0.0	53.0	00.0	140	breathing air
135	11.30	11.2	9.8	6.2	87.0	55.0	100	Normal, breathing air. 8/26
								Gassed, 4.29 p. m. 8/26
	2.15	17.0	12.9	0.0	76.0	00.0	100	breathing air
	2.40	16.6	11.9	1.1	71.0	6.0	120	breathing oxygen
	3.25	16.2	14.1	2.1	87.0	12.0	120	breathing oxygen
	4.30	16.1	9.3	0.0	51.0	00.0	120	breathing air
136	3.00	18.6	16.8	2.7(?)	90.0	14.0	120	Normal, breathing air. 8/26
								Gassed, 9.06 a. m. 8/27
	9.00	21.5	17.2	5.9	80.0	27.0	130	breathing air. 8/28
	9.40	21.5	19.5	9.6	90.0	44.0	140	breathing pure oxygen
	10.05	21.5	21.7	7.8	100.0	36.0	135	breathing pure oxygen
	10.30	21.5	16.8	5.1	78.0	23.0	130	breathing air

The Influence of Venesection and Infusion upon Oxygen Changes of the Blood During Oxygen Administration.

It is apparent from the study of the blood oxygen as outlined above that oxygen alone cannot be of more than temporary value in relieving the effects of gas poisoning. The next logical step in the development of the possible therapeutic use of oxygen is the study of the blood following bleeding and infusion plus oxygen administration. A large number of experiments have been carried through. From the results of the experiments on the dogs which were placed in the oxygen chamber after venesection it is clearly evident that the respiratory function of the blood is not improved by venesection alone. Although no study of the influence of venesection on the arterial and venous content of the blood was made immediately after venesection, nevertheless the results which are given on pages 295 and 299 of the Appendix, show that the beneficial effects of breathing oxygen instead of air are considerable, although practically the same as the effects obtained when venesection is not performed. The details of these may be found in the Appendix, pages 295–309. From these data it is quite evident that bleeding does not materially alter conditions relative to the respiratory functions of the blood. However, at the time of venesection the oxygenation of the blood and tissues is not, in general, markedly deficient. The respiratory function of the blood is distinctly better when an animal is breathing oxygen than when ordinary air is breathed. The order of change is not, however, appreciably different from that which obtains when an animal breathes oxygen without venesection, as is seen by comparing Tables CLXV–CLXVIII, Appendix, pages 299–309.

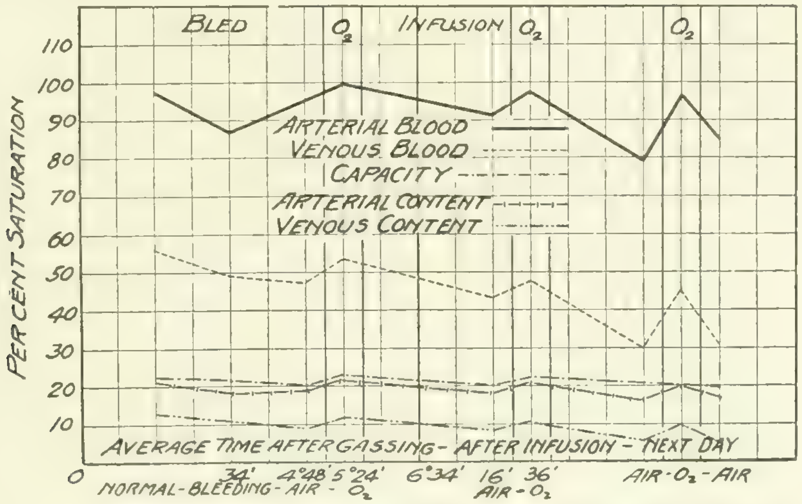

Fig. 52. THE INFLUENCE OF OXYGEN UPON THE BLOOD OF GASSED DOGS AFTER TREATMENT.

Bleeding followed by infusion may be said to have a decidedly beneficial effect upon the oxygenation of the blood. This is indicated by the fact that even when an animal is breathing air the venous blood carries more oxygen, which may be interpreted to mean that the tissues are being better supplied with oxygen. Oxygen administration at this time results, in general, in restoring the arterial blood to limits near the normal and in raising appreciably the venous saturation. These observations may perhaps be expressed best graphically (see Figures 52 and 53). In Fig. 52 the average curves of four dogs are presented, while in Fig. 53 curves drawn from the average figures obtained with 20 animals are represented. It would appear from these facts that bleeding plus infusion so changes the physical character of the blood as to render possible a more complete oxygenation of tissues. The interpretation placed upon these results is that infusion decreases the viscosity of the blood, at least temporarily, so that capillary circulation is improved and, as a consequence, more adequate tissue respiration is possible. The dissociation of the oxyhemoglobin is probably also increased in accordance with the results of Barcroft on the effect of electrolytes on the dissociation curve of hemoglobin. It seems, therefore, that the optimum conditions for the use of oxygen are in connection with bleeding and infusion of salt solution. No single procedure is adequate, a combination of the three approaches the optimum treatment.

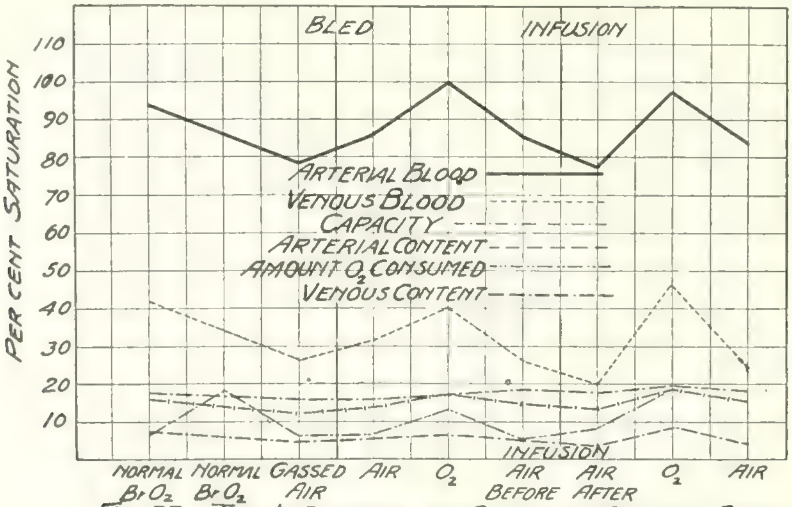

Fig. 53. THE INFLUENCE OF OXYGEN UPON THE BLOOD OF GASSED DOGS AFTER TREATMENT.

The Influence of Gassing and Treatment upon the Volume of Air Breathed and upon the Pulse.

The extent of oxygenation of the blood will depend directly upon the rate of respiration and the volume of air breathed per minute and upon the circulation rate through the lungs. It therefore becomes of importance to determine these factors if a complete knowledge is desired concerning changes induced by gassing. Owing to insurmountable obstacles the circulation rate could not be determined in this investigation. The volume of air breathed and the respiration rate, however, have been followed in a measure and the observations indicate that shortly after gassing the respiration is markedly increased, but that the volume of air breathed per minute is slightly less than normal. In other words, there is present rapid, shallow breathing and undoubtedly less air, hence oxygen is in contact with blood in the lungs during a given period on the assumption that the circulation rate is constant.

Bleeding has no noticeable influence upon either the rate of respiration or the volume of air breathed per minute. Infusion, however, causes a rapid increase in both (see Fig. 54). Oxygen administration does not exert a marked influence in either particular.

The pulse rate is distinctly decreased soon after gassing, but gradually increases to a maximum several hours later. If oxygen is administered during the period of the increasing heart beat, only a slight decrease in the rate is to be noted. This is well illustrated in Fig. 54, an average curve from the results obtained with 9 dogs. (For data see Appendix, page 309)

Respiratory Exchange.

From the data (see Appendix to Chapter XV, page 309) collected in the study of the respiratory exchange it may be said that both oxygen consumption and carbon dioxide production are distinctly lowered by exposure to phosgene. Breathing oxygen under these circumstances increases the oxygen consumption. In general, oxygen administration increased the carbon dioxide production to a slight degree.

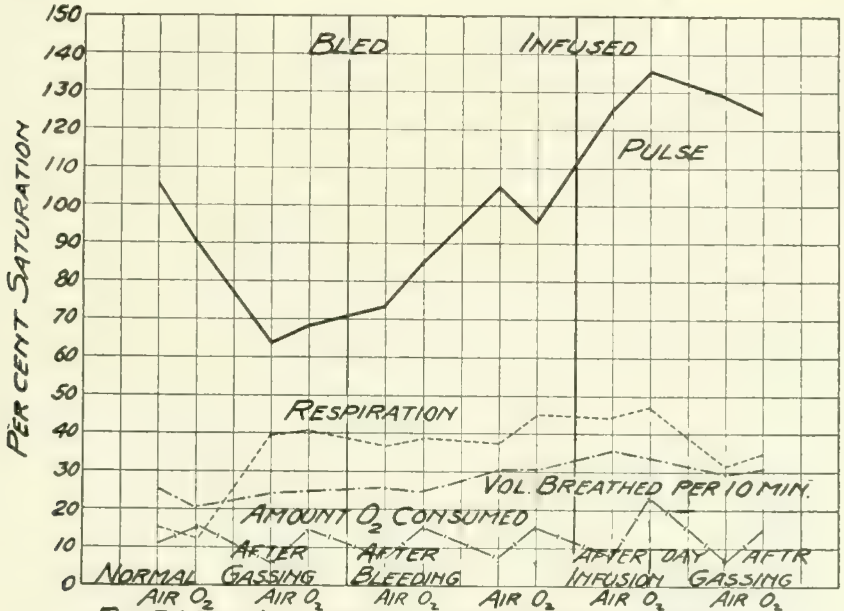

Fig. 54. THE INFLUENCE OF OXYGEN UPON THE PULSE AND RESPIRATION RATE IN GASSED DOGS.

Bleeding causes a slight increase in oxygen consumption, although still below normal. It is evident that venesection does increase the animals' ability to obtain oxygen since it may be seen that in Series 4, see Appendix, page 309, when breathing air the oxygen consumption was increased by 3 per cent on venesection. In Series 5, see Appendix, page 309, there is an increase of 10 per cent, the oxygen consumption being still 33 per cent lower than normal. When breathing oxygen, however, after bleeding the oxygen consumption is raised, in Series 4, 12.8 per cent above the values obtained when the animal was breathing oxygen before bleeding, the oxygen consumption being now only 12 per cent below normal. On the other hand, carbon dioxide production is appreciably increased.

Infusion raises the oxygen consumption and, in general, the carbon dioxide production. Oxygen administration after infusion brings the oxygen consumption back to the normal level and may indeed carry it above (see Figures 53 and 54). This should be considered in connection with the percentage saturation of arterial and venous blood. As has been pointed out above, the venous blood carries more oxygen after infusion than before. The administration of oxygen after infusion results practically in complete saturation of the arterial blood as well. The oxygen consumption is equal to or greater than normal, while the arterial blood is almost completely saturated, and the venous percentage saturation indicates that the tissues are getting an ample supply of oxygen.

The conclusion is, therefore, warranted that the method of treatment involving venesection, infusion and oxygen administration is indicated for the reestablishment of normal conditions in the respiratory functions of the blood in an animal gassed with phosgene. It should be emphasized that oxygen administration alone is entirely inadequate to combat the effects of phosgene poisoning, inasmuch as this procedure does not eliminate the primary cause, namely, the concentration of the blood. When treatment succeeds in restoring blood concentration to a more nearly normal level, oxygen administration is of decided benefit.

CHAPTER XVI

PHOSGENE POISONING IN MAN

From a practical standpoint treatment of phosgene poisoning must be considered of the greatest significance inasmuch as this was the principal lethal gas being employed in the latter part of the war by the enemy. A number of phosgene cases were observed by the writer which, however, were not available for testing the treatment inasmuch as these patients were French soldiers and hence not under the jurisdiction of the American Army Medical Officers. From the clinical pictures presented by these gassed individuals it became quite evident that the conditions existing in man and the dog are remarkably similar if not identical. From a clinical viewpoint the human gassed cases observed could very readily be divided into three groups (a) those lightly gassed, the chief symptoms being slight dyspnoea; (b) so-called *blue* cases, with very pronounced respiratory distress and evidence of edema; (c) the *gray* cases, with pronounced edema and almost utter inability to breathe. In some of the latter cases a shock-like condition was also evident.

There is little doubt that these different states could very well be correlated with those existing in the gassed animal. It is a distinct impression that the gray case is a later condition of the blue case, and that the gray state could be successfully prevented by correct bleeding in the early part of the stage culminating in the blue appearance. In the early part of the blue stage the blood is only moderately concentrated, whereas in the gray case concentration has proceeded to a point where bleeding in many instances is impossible. From experimental considerations bleeding is not indicated in the gray stage. On the other hand, with the excessive concentration of the blood present under these circumstances, there is every indication for the introduction of fluid into the body, either by way of the mouth or by the intravenous path. The only objection that can be made against infusion is that it may aggravate edema. There is, however, no evidence that such a condition follows as a sequence to proper infusion. Indeed, experimental observations point to the fact that the edema evoked by phosgene in goats is not aggravated by infusion of salt solution (see Chapter XIII, page 157). Moreover, it seems that even though edema should be increased somewhat by such a measure harm would not necessarily follow if it is accepted that *the cause of death is the concentration of the blood and not the edema per se.* Certain it is that experimentally infusion of salt solution into the blood stream of animals in a condition analogous to the gray state in man is beneficial rather than injurious.

The application of the principles of experimental treatment to the blue stage in man is not so clear-cut as in the case of the gray stage. It would be necessary to accurately follow such cases by the criteria, hemoglobin and temperature, before dogmatic statements could be formulated. Certain it is, however, that many gassed cases could undoubtedly be prevented from becoming blue cases by the application of the principles, especially the early bleeding, previously formulated.

Oxygen administration is certainly distinctly indicated at certain stages of phosgene poisoning, experimentally and in man. Oxygen alone, however, at any stage is of very little value, as it does not remove or alleviate the cause of the trouble, namely, the concentration of the blood. As an adjuvant to the experimental treatment proposed its influence would tend to restore normal conditions in the respiratory functions of the blood. Under these circumstances the proper use of oxygen is of great value.

As has been stated previously the exact correlation of the experimental conditions with those existing in man were in a fair way of being realized and the method of treatment put to the test when all operations ceased because of the signing of the Armistice.

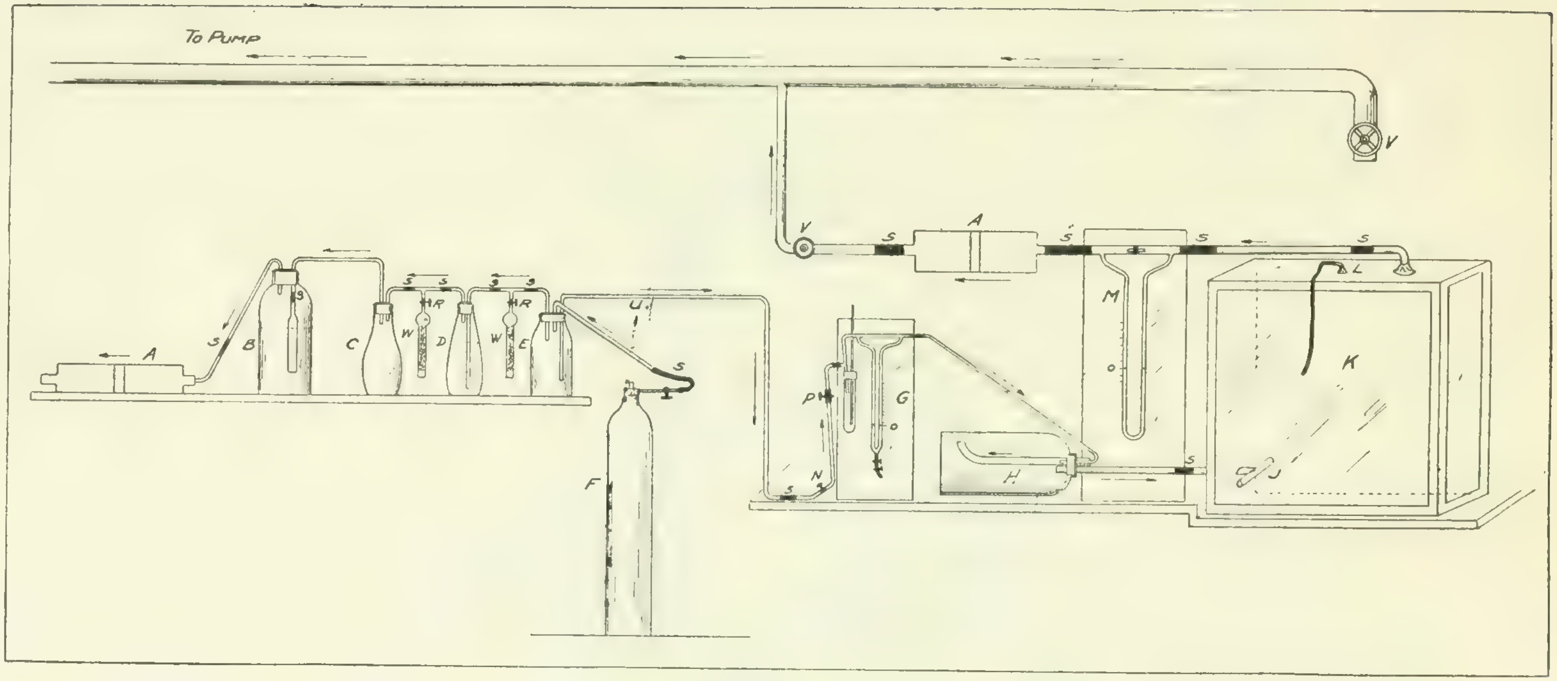

Fig. 55.

APPENDIX

CHAPTER II

The Methods of Gassing

A. METHODS FOR CHLORINE AND PHOSGENE.

Description of Chlorine and Phosgene Gassing Apparatus (Fig. 55).

Gas passes from gas cylinder (F) to bottle (E), where a certain pressure is always maintained by means of concentrated H_2SO_4 in (D). The excess of gas passes through (C) into (B), where most of it is absorbed. Any unabsorbed gas passes into the metal absorber (A), where it is completely taken up. The safety valves (R) are closed during all gassings. They are opened when the apparatus is not in use to prevent the liquids in (D) and (B) from being siphoned to the right.

From the bottle (E) the gas passes by means of a delivery tube to the gas flowmeter (G) which measures the rate of flow of the gas. The gas flow is controlled by the glass stopcock (N) and pinchcock (P). From here the gas passes into the glass mixer (H). Air is also drawn into the mixer (H) by means of a suction pump, and the rate of flow of air is measured by the flowmeter (M) which is controlled by the valve (V). The mixture of air and gas then passes through the T-tube (J) into the gassing chamber (K).* It leaves the chamber from the top, passing through the air flowmeter (M), then into the metal absorber (A), where most of the gas is taken up, and then passes out through the suction pump and up through the flue.

Samples of the mixture of gas and air are taken at three-minute intervals from the top of the gassing chamber (K) by means of the outlet tube (L).

Fig. 55. Gassing Apparatus.

A — Absorption cans containing soda-lime and charcoal.
B — Absorption bottle containing a saturated solution of caustic soda.
C — Safety bottle.
D — Bottle containing concentrated H_2SO_4.
E — Empty bottle (gas supply).
F — Gas cylinder.
G — Gas flowmeter.
H — Mixer (for gas and air).
J — Metal T-tube.
K — Gassing chamber.

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*A standard rate of flow through the chamber of 250 liters per minute was adopted. With this rate, a desired concentration can be attained in from 2 to 4 minutes.

L — Delivery tube for samples.
M — Air flowmeter.
N — Glass stopcock for controlling flow of gas.
P — Pinchcock for controlling flow of gas.
R — Pinchcocks.
S — Rubber connections.
U — Gas delivery tube.
V — Valves regulating flow of air.
W — Calcium chloride tubes.

Chlorine was determined by bubbling through KI solution, a Folin bulb insuring efficient absorption. The liberated iodine was then titrated with N/100 sodium thiosulphate, using starch paste as indicator. The samples were collected by water displacement, a one-liter flask being used. At the lower concentrations, however, the size of the sample was doubled.

The concentrations of the gas are calculated for 0° and 760 mm., assuming that the laws for an ideal gas hold, and that a gram molecule of the substance occupies 22.4 liters.

Experience has shown that the above method is accurate within about 5% (see below for method of estimation).

The method of gassing with phosgene was similar to that of chlorine with the exception of the sampling and method of analysis (see below for method of analysis).

In phosgene gassing five-liter samples of gas mixture were taken. Five samples were run through for each gassing the first three minutes after the gassing started and the remainder every five minutes from the time the first sample was started. The time required to run a sample was three minutes. Each sample was run through one tube containing 25 cc. of alcoholic soda (4%) which absorbed the phosgene. The sample was then analyzed for chlorine by means of the Mohr method, and the phosgene determined in parts of gas per million parts of air at 0°.

Reactions

Phosgene ($COCl_2$)

$$4\ NaOH\ (\text{alcoholic}) + COCl_2 \longrightarrow 2\ NaCl + Na_2CO_3 + 2\ H_2O$$

$$2\ NaCl + 2\ AgNO_3 \longrightarrow 2\ \underset{\text{white}}{AgCl} + 2\ NaNO_3$$

$$2\ AgNO_3 + K_2CrO_4 \rightleftarrows \underset{\text{red}}{Ag_2CrO_4} + 2\ KNO_3$$

Excess Indicator

Chlorine (Cl_2)

$$2\ KI + Cl_2 \longrightarrow 2\ KCl + I_2$$

$$2\ Na_2S_2O_3 + I_2 = 2\ NaI + Na_2S_4O_6$$

(a) *Method of Analysis for Chlorine.*

Solutions required:

1. (1) N/100 $Na_2S_2O_3$ solution (use N/200 $Na_2S_2O_3$ for concentrations of chlorine less than 200 parts per million).
2. (2) N/100 KIO_3 solution.
3. (3) Starch solution.
4. (4) A 2% potassium iodide solution.

First it is required to standardize the $Na_2S_2O_3$ solution which has been made up approximately N/100. In order to do this about 5 grams of potassium iodide are dissolved in an Erlenmeyer flask in a small amount of water. Five cc. of diluted HCl (4 parts H_2O and 1 part concentrated HCl) are added. A measured quantity of N/100 KIO_3 solution (accurately made up in a volumetric flask) is then added. 20-25 cc. is a convenient amount. On the addition of the KIO_3 a certain amount of iodine is liberated equivalent to the amount of KIO_3 used.

$$2\ KIO_3 + 10\ KI + 12\ HCl = 6\ I_2 + 12\ KCl + 6\ H_2O$$

The solution is then titrated with the $Na_2S_2O_3$ solution until the discharge of the iodine color. Near the end of the reaction, however, starch solution should be added to the flask, and the endpoint of the reaction will be the disappearance of the blue color.

$$I_2 + 2\ Na_2S_2O_3 = 2\ NaI + Na_2S_4O_6$$

The strength of the $Na_2S_2O_3$ solution can then be calculated in the following manner: The KIO_3 solution being exactly .01N, the relation to normal of the $Na_2S_2O_3$ solution can be found by dividing the number of cc. of KIO_3 used by the number of cc. of $Na_2S_2O_3$ used.

1 cc. N $Na_2S_2O_3$ solution = .035 grams of chlorine.

1 cc. N/100 $Na_2S_2O_3$ solution = .00035 gram of chlorine or .35 milligram of chlorine.

1 cc. of XN $Na_2S_2O_3$ solution = X (.35) milligram of chlorine.

Now in order to calculate how many parts of chlorine per million parts of air are equivalent to 1 cc. of N/100 $Na_2S_2O_3$ proceed as follows:

According to the gas laws and assuming that they hold, the molecular weight of chlorine (71.0 grams) occupies 22.4 liters at 0° and 760 mm.

Then .35 milligrams of chlorine, which is equivalent to 1 cc. N/100 $Na_2S_2O_3$, will occupy $\left[\frac{22{,}400}{70{,}000} \times .35\right]$ cc. at 0° – 760 mm. or .112 cc.

Therefore 1 cc. N/100 $Na_2S_2O_3$ = .112 cc. Cl_2
and 1 cc. N/200 $Na_2S_2O_3$ = .056 cc. Cl_2
also 1 cc. of XN $Na_2S_2O_3$ = X (.112) cc. Cl_2

It can now easily be seen that if an air-chlorine mixture sample of exactly one liter is taken and 1 cc. N/100 $Na_2S_2O_3$ used in the titration of it, the mixture contains .112 cc. Cl_2 per 1000 cc. of mixture or 112 parts of chlorine per million parts of air-gas mixture. And the same process of reasoning and calculation is used for the various strengths of $Na_2S_2O_3$ solutions. Thus 1 cc. N/200 $Na_2S_2O_3$ solution = 56 parts per million of chlorine.

Of course, if a two- or three-liter sample of the air-gas mixture is taken, the accuracy of the determination is increased just that many times. For example, taking a two-liter sample, 1 cc. of $Na_2S_2O_3$ (N/100) would equal .112 cc. Cl_2 per 2000 cc. of mixture or 56 parts of chlorine per million parts of mixture. If a N/200 $Na_2S_2O_3$ solution were used, 1 cc. would equal .056 cc. Cl_2 per 2000 cc. of mixture or 28 parts of chlorine per million parts of mixture. It can be seen that the more dilute the $Na_2S_2O_3$ solution used, and the larger the sample taken, the greater will be the accuracy of the determination. That is why it is desirable to fulfill the latter conditions when very low concentrations of chlorine are used, say 200 or less parts per million. When concentrations of about 800 parts per million are used, sufficient accuracy obtains by taking a one-liter sample (take one minute in drawing) and using N/100 $Na_2S_2O_3$. The determination can be made to an accuracy of within ± 12 parts per million under these conditions or approximately 1%.

Taking of Sample and Analysis.

A sample of the air-gas mixture is taken by passing a measured volume (1, 2, 3 liters) through about 25 cc. of a 2% KI solution. This solution should absorb every trace of chlorine. The liberated iodine is titrated with the $Na_2S_2O_3$ solution in an Erlenmeyer flask. Calculation of the concentration is made on the basis of the data given above.

$2\ KI + Cl_2 = 2\ KCl + I_2$.

Note: Samples should be taken every three or five minutes.

(b) *Method of Analysis for Phosgene.*

Solutions required:

(1) N/10 Sodium Chloride solution:—Dissolve 5.846 grams of fused C.P. NaCl in one liter of distilled water. Dilute 100 cc. of this stock solution to one liter in order to obtain a N/100 salt solution.

(2) N/100 Silver Nitrate solution:—Dissolve 1.700 grams of pure dried silver nitrate crystals in one liter of distilled water.

(3) Potassium Chromate Indicator:—Dissolve 50 grams of neutral potassium chromate in a small amount of distilled water; add enough silver nitrate to produce a slight red precipitate; filter and make up the filtrate to 500 cc. with distilled water.

(4) Concentrated caustic soda solution:—Dissolve 300 grams C.P. caustic soda in 800 cc. H_2O and make up to 1 liter.

(5) 3% caustic soda solution in alcohol:—Dilute 100 cc. of solution to 250 cc. with H_2O and make up to 1 liter with 95% alcohol.

(6) Normal Nitric Acid:—Dilute 65 cc. nitric acid sp. gr. 1.42 to 1 liter with distilled water.

(7) N/100 Nitric Acid:—Dilute 100 cc. of normal nitric acid to 1 liter in order to obtain N/10 HNO_3 solution.

(8) Phenolphthalein Indicator:—Dissolve 1 gram in 100 cc. of alcohol.

Determination of Phosgene.

Absorb the $COCl_2$ in 25 cc. of 3% alcoholic soda and wash into an Erlenmeyer flask. (Five liter samples were taken in every case, and five samples were taken during a gassing period, *i.e.*, 30 minutes.) The volume should be about 75-100 cc. Nearly neutralize the solution with N/1 HNO_3 using phenolphthalein as the indicator, and get the exact end point with N/10 HNO_3. Then add 0.5 cc. N/10 HNO_3 in excess. (This will make the solution neutral to phenolsulphonthalein.)

Add now 1.0 cc. of 10% K_2CrO_4 solution and N/100 $AgNO_3$ from a burette until a distinct brown color is produced. It is best to use the same amount, say 10.0 cc., of $AgNO_3$ in every case. Then titrate back to loss of brown color with N/100 NaCl solution.

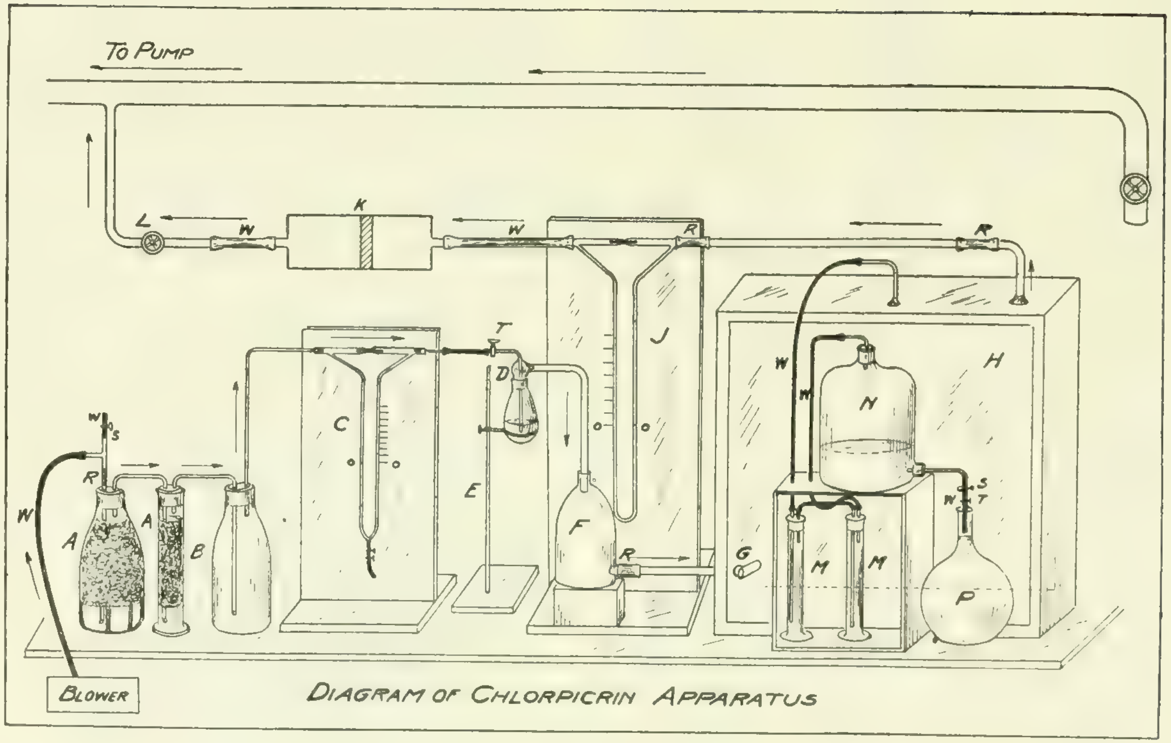


DIAGRAM OF CHLORPICRIN APPARATUS

The $AgNO_3$ solution should be standardized under exactly the same conditions used in the actual determination of $COCl_2$. In the presence of the alcohol and salts the $AgNO_3$ has a lower value (about 75%) in titrating chloride than it has on a solution of pure NaCl in distilled water.

The N/1 HNO_3 may be made up roughly. Its strength need not be accurately known.

Phenolphthalein is used because phenolsulphonthalein obscures the end point of the chloride determination. The excess of N/10 HNO_3 is to make up the difference in end point of the two indicators.

The amount of K_2CrO_4 used should be kept constant in the different determinations. 1.0 cc. of 10% solution was found to be the smallest amount that would give a good end point.

The maximum error at a concentration of 100 was 8 parts per million. Usually the error was within 4 parts per million.

Note: Care must be observed to use chlorine-free reagents and water.

As to the calculation of results:

1 cc. N/100 $AgNO_3$ = .495 mg. $COCl_2$.

99 grams of $COCl_2$ (its molecular weight) would occupy 22,400 cc. assuming that the gas laws hold true.

Then .495 mg. would occupy $\left(\frac{22{,}400}{99{,}000} \times .495\right)$ cc. or .112 cc.

Therefore, 1 cc. N/100 $AgNO_3$ = .112 cc. $COCl_2$ gas or 112 parts of gas per million parts of air if one-liter samples were taken.

Since five-liter samples were taken, 1 cc. N/100 $AgNO_3$ = 22.4 parts per million.

B. METHODS FOR CHLORPICRIN.

Description of Chlorpicrin Gassing Apparatus

Since chlorpicrin has a high boiling point and is a liquid at ordinary temperatures air was passed through the liquid in order to convert it into a gas.

Air which is furnished during the gassing by a blower is passed through the bottles (A–A) containing crude anhydrous calcium chloride which takes up any moisture, through the empty bottle (B) and is measured by the small air flowmeter (C). The rate of flow of air is controlled by the stopcock (S). From the small flowmeter the air passes through the liquid chlorpicrin in flask (D) where it becomes saturated with chlorpicrin gas and then into a glass mixer (F). Here it is mixed with the main supply of air (250 liters per minute) which is measured by the large flowmeter (J) and controlled by the valve (L). From the mixer (F) the mixture of air and gas passes into the gassing chamber (H) by way of the metal T-tube (G). The mixture of air and gas passes out of the chamber at the top by means of a delivery tube and then through the flowmeter (J) into the metal absorber (K) con-

Description of Apparatus for Chlorpicrin.

A — Air drying bottles containing crude anhydrous calcium chloride.
B — Air pressure bottle.
C — Flowmeter containing albolin oil for measuring rate of flow of air (10 to 20 cc. per minute).
D — Specially prepared flask for holding liquid chlorpicrin.
E — Ring stand.

F — Glass mixer (air and gas).
G — Three-way brass delivery tube.
H — Gas chamber.
J — Large flowmeter containing albolin oil for measuring rate of flow of air (250 liters per minute).
K — Metal gas absorber (contains charcoal and soda-lime).
L — Valve.
M — Sampling tubes (contain 25 cc. alcoholic Na_2SO_3—alcohol and water 1:1).
N — Three-liter flask (graduated).
R — Rubber connections.
S — Stopcocks.
T — Glass stopcock.
W — Rubber tubing.

taining soda-lime and charcoal which remove most of the gas. From here the air passes out through the metal pipe to the suction pump.

It was found that the temperature of the room had a marked effect upon the amount of gas passing into the chamber. The small flowmeter was calibrated at room-temperature (20° C.). If the temperature of the room was below or above (20°) the desired concentration was obtained by raising or lowering the flowmeter beyond the point corresponding to the concentration at 20°.

It was necessary also to raise the small flowmeter somewhat after the first sample was taken. This was particularly true in the case of high concentrations, for the liquid in flask (D) became very cool after air was passed through a short while and, consequently, the degree of saturation of chlorpicrin gas became less.

Procedure in Taking Samples with Chlorpicrin.

The time employed for a gassing with chlorpicrin was one-half hour. During the gassing three samples of gas mixtures were taken from the gassing chamber (H) as shown in the diagram; the first, second and third being taken five, fifteen and twenty-five minutes respectively after the gassing was started. Three-liter samples were taken in every case. Each sample was passed through two sampling tubes containing 25 cc. each of alcoholic sodium sulphite Na_2SO_3 which absorbed the chlorpicrin. The time required for each sample was between three and four minutes. Both tubes were then combined and analyzed for chlorine by means of the Volhard method and the chlorpicrin determined in milligrams per liter and parts of gas per million parts of air at O°.

(a) *Method of Analysis of an Air Mixture of Chlorpicrin* (CCl_3NO_2)

Solutions required:

(1) N/100 Sodium Chloride (NaCl) solution:—Dissolve 5.846 grams of fused C.P. NaCl in 1 liter of distilled water. Dilute 100 cc. of this stock solution to 1 liter in order to obtain a N/100 salt solution.

(2) N/100 Silver Nitrate Solution:—Dissolve 1.700 grams of pure dried silver nitrate crystals in 1 liter of distilled water.

(3) N/100 Potassium (or Ammonium) Sulphocyanate Solution:—As both of these salts are hygroscopic and cannot be dried without decomposition, dissolve approximately the right amount (10 grams KCNS or 9 grams NH_4CNS) in 1 liter of distilled water. Dilute 100 cc. of this stock solution to 1 liter in order to obtain a N/100 solution.

(4) Ferric Alum Indicator:—Prepare a cold saturated solution of ferric alum to which enough nitric acid has been added to remove the brown color.

(5) Alcoholic-sulphite absorbing solution:—Dissolve 40 grams of chlorine-free sodium sulphite (Na_2SO_3) in 500 cc. distilled water and dilute to a liter with 95% alcohol.

A relative standard between the N 100 $AgNO_3$ and approximately N 100 NH_4CNS solutions is necessary. In order to obtain this a measured quantity of N 100 $AgNO_3$ solution is diluted to about 100 cc. One cc. of ferric alum indicator is added. The solution is then titrated with the NH_4CNS solution until a pink color persists throughout the solution which is being titrated. To find how many cc. of N 100 $AgNO_3$ are equivalent to 1 cc. of NH_4CNS solution, divide the number of cc. of $AgNO_3$ taken, by the number of cc. of NH_4CNS used. Let us say for purposes of explanation in future calculations that this value is X.

The equation of this reaction is $AgNO_3 + NH_4CNS = AgCNS + NH_4NO_3$.

The pink color is due to formation of $Fe(CNS)_3$ by a drop excess of NH_4CNS and the indicator.

Having done this, the next step is to find the actual strength of the $AgNO_3$ solution. Take a measured quantity of N/100 NaCl solution and add an excess of $AgNO_3$ solution. Add 1 cc. of ferric alum indicator, shake up with a small amount of ether (in order to coagulate the AgCl formed), dilute to 100 cc. and titrate the excess $AgNO_3$ with the NH_4CNS solution.

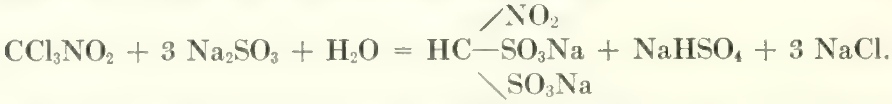
The equations are $AgNO_3 + NaCl = AgCl + NaNO_3$.
$AgNO_3 + NH_4CNS = AgCNS + NH_4NO_3$.

The reason for using ether to coagulate the AgCl is because AgCNS is more insoluble than AgCl. Therefore each drop of NH_4CNS solution in excess will react with the AgCl to form AgCNS and the red end point will constantly disappear. When the AgCl is in coagulated form, this will not take place so easily.

The calculation is as follows: Multiply the number of cc. of NH_4CNS used, by the value of X obtained from the relative standard. Subtract this result from the number of cc. of $AgNO_3$ taken. The remainder will be the number of cc. $AgNO_3$ equivalent to the cc. of NaCl taken. (This same calculation must be made in every case in the actual analysis of chlorpicrin also, except that in that case the remainder will equal the number of cc. of $AgNO_3$ equivalent to the amount of chloride from the chlorpicrin in the sample plus the chloride in the blank.) The actual standard of the $AgNO_3$ is found by dividing the number of cc. of NaCl taken by the number of cc. of $AgNO_3$ used. Of course, the $AgNO_3$ has been made up in such a way that it is very nearly equal to the NaCl solution in strength, that is to say, N/100.

Actual Method of Analysis.

The air mixture—three-liter samples—is bubbled through two tubes containing 25 cc. of 4% alcoholic Na_2SO_3 solution each. Three such samples were taken during each gassing. The contents of the tubes are then washed into a 250 cc. flask and boiled gently for 10 minutes under a water-condenser. Then the alcohol is distilled into a second flask of Na_2SO_3 to collect volatile chlorides. This flask is boiled for 10 minutes under a water condenser and then the alcohol is distilled off through an air condenser. The solution from both flasks is united and boiled down to a small volume. About 15 cc. (an excess) of N/100 $AgNO_3$ solution are added and then 15 cc. of concentrated HNO_3 and the solution boiled until the AgCl is all coagulated. Cool, dilute to 100 cc. and titrate the excess of $AgNO_3$ with N/100 NH_4CNS solution, using ferric alum as an indicator.



$$CCl_3NO_2 + 3\ Na_2SO_3 + H_2O = HC\begin{matrix} \diagup NO_2 \\ -SO_3Na \\ \diagdown SO_3Na \end{matrix} + NaHSO_4 + 3\ NaCl.$$

A blank must be run through first, following exactly the conditions of the analysis and using the same amount of alcoholic Na_2SO_3 solution as in the actual analysis. The amount of $AgNO_3$ used for this blank, call it Y, must be subtracted from every subsequent analysis. Then the calculation of the result of an analysis would be as follows: Multiply the number of cc. of NH_4CNS used, by the value of X. Subtract this number from the number of cc. of $AgNO_3$ taken. This will give the actual number of cc. of $AgNO_3$ used. Subtract Y, the blank, from this result, and we get the number of cc. of N/100 $AgNO_3$ equivalent to the chlorpicrin in the sample. 1 cc. N/100 $AgNO_3$ = .5 mg. chlorpicrin.

Assuming that the gas laws hold true, the molecular weight of chlorpicrin as a gas at 0° and 760 mm. would occupy 22.4 liters. And .548 mg. would occupy $\left(\frac{22{,}400}{164{,}500} \times .548\right)$ cc. or .0747 cc. of CCl_3NO_2 gas.

Therefore, 1 cc. N/100 $AgNO_3$ = .0747 cc. CCl_3NO_2 gas
= 74.7 parts of gas per million of air if a one-liter sample of mixture is taken. And when a three-liter sample of air-gas mixture is taken, 1 cc. N/100 $AgNO_3$ would equal $\frac{74.7}{3} = 24.9$ parts of CCl_3NO_2 gas per million parts of air.

The maximum error of this determination would be ± 5 parts per million.

The "loss in weight method" is also used in determining the amount of chlorpicrin used in a gassing and, therefore, the concentration. If the flask containing the chlorpicrin is weighed before and after the gassing, the difference in weight gives the amount of chlorpicrin passed into the chamber. If the air flowmeter is calibrated to liters per minute, by dividing the loss in weight by the total number of liters, the concentration of CCl_3NO_2 in milligrams per liter is obtained.

(b) *Loss in Weight Method for Determination of Chlorpicrin in Milligrams per Liter and Parts Gas per Million Parts Air.*

As a check on the analysis the loss in weight method was used for every gassing. This method consisted in weighing the flask D plus gas before and after each gassing, the difference in weight being the number of grams of chlorpicrin actually used. The number of milligrams per liter and parts of gas per million parts of air were readily calculated. The difference in results between the loss in weight method and the method of analysis was evidently due to the dog taking up some of the gas, for both methods checked rather accurately when the gassing was run without a dog in the chamber.

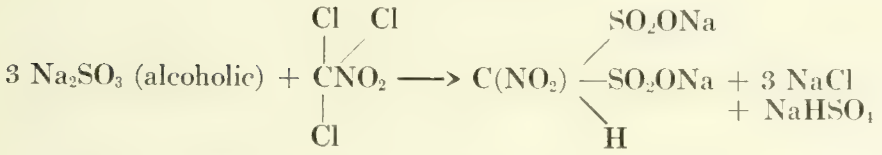
At 0° 760 mm. *22.4 liters = G.M.V.*

1 cc. N/100 $AgNO_3$ = 0.07466 cc. CCl_3NO_2
1 cc. N/100 $AgNO_3$ = 74.66 ppm. CCl_3NO_2
1 cc. N/100 $AgNO_3$ = 0.548 mg. CCl_3NO_2
0.548 : 74.66 = 1.0 : X
X = 136 ppm. = 1.0 mg. CCl_3NO_2 gas.

$$\text{Number of mg. } CCl_3NO_2 \text{ gas per liter used in a gassing} = \frac{\text{No. grams used}}{7500 \text{ liters}}$$

$$\text{Molec. weights} \begin{cases} CCl_3NO_2 = 16.44 \\ AgNO_3 = 169.97 \end{cases}$$

Reactions.



$$2\,HNO_3 + 2\,Na_2SO_3 \xrightarrow{O_2} 2\,Na_2SO_4 + H_2O + \overline{2\,NO_2}$$

$$AgNO_3 + NaCl \longrightarrow \frac{AgCl}{\text{white}} + NaNO_3$$

$$\left\{\begin{array}{l} AgNO_3 + NH_4SCN \longrightarrow AgSCN + NH_4NO_3 \\ \text{Excess} \\ FeSO_4 + 6\,NH_4SCN \rightleftarrows 2\,\dfrac{Fe(SCN)_3}{\text{red}} + 3(NH_4)_2SO_4 \\ \text{Indicator} \end{array}\right\}$$

TYPICAL EXAMPLES OF RESULTS OBTAINED BY METHOD OF GASSING

Parts of Chlorine per million of air.
Samples from 10 experiments.

Time in minutes	*Experiments 1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
3	852	851	886	832	788	864	853	864	896	832
5	853	851	896	853	767	832	842	864	842	821
13	864	830	842	853	886	875	864	832	853	864
18	842	830	842	853	886	853	864	821	810	864
22	864	840	875	886	875	875	853	821	810	864
27	865	842	875	853	875	875	832	810	821	821

Parts of Phosgene per million of air.
Samples from 10 experiments.

Time in minutes	*Experiments 1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
3	85	95	88	99	92	62	76	76	88	81
5	81	97	83	92	88	60	81	79	90	81
10	81	97	83	95	83	60	76	76	88	81
20	85	97	88	95	90	65	79	74	92	85
25	92	97	88	90	92	58	79	79	92	88

Parts of Chlorpicrin per million of air.
Samples from 10 experiments.

Time in minutes	*Experiments 1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
5	117	117	105	59	118	116	125	123	81	77
15	112	117	100	59	118	111	134	118	81	77
25	110	105	100	55	116	111	134	116	70	70

APPENDIX

CHAPTER III

Data on Respiration

Phosgene

TABLE XCII

Rate of Respiration after Phosgene Gassing

Animals that Die

Concentration of phosgene 40-80 parts per million air (0.17-0.35 mgm. per liter)

Concentration	*50*	*47*	*50*	*46*	*46*	*50*	*42*	*52*	*52*	*54*	*54*	*55*	*52*	*55*
Dog	*P 661*	*701*	*709*	*717*	*721*	*707*	*708*	*639*	*642*	*643*	*645*	*647*	*671*	*673*
Hours after exposure														
Normal	18	–P*	–P	24	24	26	–P	40	16	26	24	26	–P	–P
1	24	84	22	14	50	52	52	32	52	56			44	
2	20		36	28	50	24		22	48	48	14	36	40	
3	26	56	24	24	44	28	20		20	24	14	68	32	28
4	36			32				32		24	18	40	38	28
5	26	52	14	24	48		32	20	16	22		38	48	24
6	32	84				36	32	28	16		28		44	
7	28							36	28	34				
8	40	82	26	44	60							32		20
9						24	30			20	42		32	
10		76						42	30			26		36
11	28		32	50		32	44			20	70		28	
12					52			42	34					38
13	38	62	52	52								64	44	
14							80		48	32				
15	56				68	50		60						112
16			40	60		48							40	
17		56										48		–P
18	60									32			56	
19			44	58		40			56					
20	56	64						96					62	
21														
22	68	64	36	64								50	80	
23						48				50				
24–27	50	–P		70					76	64		60	80	
28–30	66	108		60									86	
31–36														
37–42														
43–48													88	

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* P = panting.

TABLE XCII (*Continued*)

Rate of Respiration after Phosgene Gassing

Animals that Die

Concentration of phosgene 40-80 parts per million air (0.17-0.35 mgm. per liter)

55	*54*	*59*	*56*	*60*	*58*	*72*	*73*	*79*	*73*	*78*	*76*	*77*	*76*	*74*	*Average*
674	*691*	*693*	*694*	*695*	*697*	*761*	*764*	*768*	*769*	*779*	*780*	*782*	*783*	*785*	
20	40	44	–P	16	11	–P	16	24	68	–P	–P	60	–P	18	34
	26	30				36	30	16		30	24		60	16	38
	20				20	36	40	24	32	30				20	31
32			28	20	40				24			80	76		35
24			30	28		40	46	16	28	152	38			24	37
26	38	22			38	44	40	16				60	48	30	33
			18	70	48		42	24	36		32				38
27	48	20	20	60		32					36	68	44		37
	52	20			36	38	48	29	76					48	43
36			24	84								70	60		42
	68	28			68	42	52	46			44				47
80			32	80											45
	136				84	40	42								59
			44											42	50
	124	36						52				–P	–P		62
											68				69
						38	46								45
														40	48
		28	48					72							49
	92										–P				58
						40	52								61
		52	68											44	54
								38							57
											64				54
		32				48	40				60			36	56
		28	68			52	32								63
			72												72
															88

TABLE XCIII

Rate of Respiration after Phosgene Gassing

Animals that Recover

Concentration of phosgene 40-80 parts per million air (0.17-0.35 mgm. per liter)

Concentration	*50*	*45*	*43*	*50*	*45*	*47*	*47*	*45*	*45*	*46*	*50*	*49*	*51*	*53*
Dog	*P 663*	*665*	*700*	*702*	*703*	*704*	*705*	*708*	*715*	*716*	*719*	*731*	*640*	*641*
Hours after exposure														
Normal	46	26	–P*	20	16	–P	16	28	20	–P	16	18	32	16
1		100	88	20		24	44	24	44	108	16	26	18	36
2	16			24	28	30	48	34	64		24	52	26	34
3	18		72		24				48	72		38		28
4	20			46		16	36	30	32	68	22		22	34
5	16	80	48	60	24	16	32		32	52		22	20	36
6	32		46		24	12	28	24	24	32	28		24	32
7	15			44								30	32	20
8			40					32					26	48
9					28		36		28	52	28			
10	18		40	20		12						36		
11								34					24	60
12	24			24	36	18	22		52	60	34			28
13			28					36				42	22	
14	24				28	24	36							
15				28					40	24	44		20	56
16					32	40		32						
17	14	74	22	24			28		40	52		44		
18											56			
19	22				24	20		40	36				28	60
20			24				20			56				
21	28	56		38							38			
22			20		40	36	38	44						
23	40			42						56		46		
24–27	28	66	36	48	24	12	68		38	54	36		20	56
28–30	40		52						56	60			32	
31–36		60								16				
37–42														
43–48	24	44												

* P = panting.

TABLE XCIII (*Continued*)

Rate of Respiration after Phosgene Gassing

Animals that Recover

Concentration of phosgene 40-80 parts per million air (0.17-0.35 mgm. per liter)

56	*55*	*51*	*55*	*58*	*53*	*59*	*51*	*52*	*73*	*75*	*76*	*79*	*76*	*76*	*72*	*Average*
644	*648*	*664*	*669*	*672*	*692*	*696*	*718*	*722*	*763*	*765*	*770*	*776*	*778*	*781*	*784*	
26	16	24		24	38	14	16	16	22	30	20	–P	10	24	26	22
56		72	60	16	76		72	36	40	32	40	64	32	26	64	47
80	16	64		8	56		52	24	48		26	60				38
80	18	68		16		46	52	20		42	32				76	44
52	18			16		44	68		44	42	30		24	28		35
36	26	64		20	42		40	20	48	52		50			92	40
		68		12		44			60		48		16	24		32
60		88			42	48				40		52			66	45
	16				44		36	24	48		48		22	40		35
80			28	12		34				60		68			84	43
	24	40			36				48		32		16	48		31
44				32		28	40			60		64				43
		32			36			28	60							35
	22		52	11		52	40									34
40		28			36						56				72	38
								44		54			32	60		40
				14			28		50			48				35
	28	40	52		52	48										40
38				16		50		40			64				40	43
		34					36			56			40	48		37
				24	56			40	56			60				42
		40														40
	30			18				40			42				72	38
48		52				50	40	28		88			40	60		49
46	28	48		16	60	68	32	36	42	88	96	60			84	48
		70	80	40	60				54			58	28	36		51
																68
		48		60												44

TABLE XCIV

Respiration Rate of Dogs Gassed with Chlorpicrin

Concentration 0.51–0.65 mgm. per liter (70–89 parts per million)

Hours after Exposure

Deaths	*Dog No.*	*Conc.*	*-1*	*1–2*	*2–3*	*3–4*	*4–5*	*5–6*	*6–7*	*7–8*	*8–9*	*9–10*	*10–11*	*11–12*	*12–13*	*13–14*	*14–15*
	8	.62	42	38	38	34	36	48	52	52	52		56		66		62
	5	.62	22		18	24	16	24	20	24		20		24		30	
Recoveries	1	.64	6	12	17		16	16	28	24	48		16		20		15
	4	.57	20	10	20		20	28	30	20	24		20		24		30
	255		24		22	28	24	24	24	26	24	24	24	32	24	24	24
	256				52	40	32	36	36	40	48	44	36	48	48	52	60
	257	.56	8	18	20	18	22	28	20	20	20	24	24	20	28	32	44
	262	.62	20	22	28	20	20	40	52	12	32	32	32	40	28		28
	263	.58	50	28	20		32	24	32	28	20	20	24	22	32	32	28
	268	.65	20	20	20	24	20	20	28	24	16	28	24	20	40	32	32
	270	.59	24	24	24		20	28	28	32	20	20	20	24	20	20	20
	275	.62	24	20	28	20	24	24	32	36	40	48	60	56	60	60	68
	278	.64	32	24	22	24	28	32	32	36	36	44	44	48	36	44	44
	279	.64	20		24	24	24	32	24	12	24	24	32	24	20		24
	280	.61	32	24	24	22	22	28	28	24	36	24	24	12	16	20	28
	281	.65	18	18	20	12	11	12	12	16	20	18	20	28	20		28
	282	.58		20	24		20	20	20	20	20	32	32	48	28	32	40
	285	.60	8	16	20		19	20	24	12	12	16	20	20	16	20	20
	289	.60	16	16	24	28	28	28	28	24	36	36	36	36	40	44	44
	290	.63	20	32	32	20	28	36	36	44	48	48	48	52	52	52	60
	295	.51	28	24	24	24	28	40	48	48	48	40		48		40	38
Average			22	20.5	24	23	23	27	29	26	30	31	30	34	31	36	35.5

TABLE XCIV (*Continued*)

Respiration Rate of Dogs Gassed with Chlorpicrin

Concentration 0.51–0.65 mgm. per liter (70–89 parts per million)

Hours after Exposure

15–16	*16–17*	*17–18*	*18–19*	*19–20*	*20–21*	*21–22*	*22–23*	*23–24*	*24–26*	*26–30*	*30–36*	*36–42*	*42–48*
	44		44		44		52		54	D			
30		36		56			48		44		D		
	28		32		40		44		40	40	42	48	72
	22		30		44			48	44	40			
24	36			34									
76	68			68									
32	36	44	44	44	40	48	44		30				
	36			36									
28	32	28	32	28	24	24				24	20		24
32	28						40		40		24		
20	20	20	20	28	20	24	20		32				
68	72	54		44									
40		40	44		48		38						
	36		48		44		40						
	28		24	32									
	28	32		30									
40	40	36	40	32	44	48					32		
24	24	24	20	28	36		32		32				24
44	44	48	40		40		48	42					24
60	60	68			43	32							
	44	40		36	38								
41	38	39	37	37	38	35	38	45	36	35	37	48	38

TABLE XCV

Respiration Rate of Dogs Gassed with Chlorpicrin

Concentration 0.66–0.80 mgm. per liter (91–110 parts per million)

Hours after Exposure

	Dog	*Conc.*	*Normal*	*½*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*
Deaths																
	247	.69	24		20	20	20	20	16	16	20	16	20	D*		
	225	.73	14		12	8		11	9	10	8	10	12	D		
	188	.75	44		12	26	16		20		16	20	25	64		
	236	.67	20		60	20		28	28	28	32	44	28	36	32	28
	216	.78	16		20	16	20	24	20	20	20	20	20	24	24	20
	251	.70	28	22	40	40		42	28	24		36	36	36	32	28
Average			24	22	28	21	19	25	20	19	19	24	23	40	29	25
Recoveries																
	2	.70		10	18		16	24	22	15	20		20		12	
	3	.66	28		92	70	64	44		24		40		24		64
	6	.75	26		38	25	48	48	20	64		52		56		54
	7	.80		28	26	27	24		24		28		30		44	
	9	.71	15	8	8	9	16	16	13	20	20		26		36	
	13	.76	20	15	56	20	24	24	24	28	32		30		36	36
	221	.77	24	28	16	16	12	18	20	20	20	20	20	18	28	32
	222	.78	20	18	16	20	18	18	32	36	36	48	52	44	36	40
	228	.75	14	8	8	6	12	9	8	8	8	8	8	7	7	7
	231	.68		48	24	28		24	24	28	28	32	16		20	36
	232	.80	14	32	18		28	28	24	28	28	28	28	28	28	28
	235	.78	12	40	24		24	16	20	20		24	20	28	28	36
	237	.68	16	28	32		28	30	24	32	32	20	28	28	32	32
	240	.75	24	32	32	30	34	28	28	32	38	28	28	36	44	36
	241	.80	32	18	22	20		16	24	24	28	24	24	28	20	20
	242	.72	20		20		20	24	24	32	24	24	20	20	44	40
	245	.75	24		20	16	16	20	20	20	16	20	20	20	16	16
	246	.71	20	20	20	12		16	20	20	16	18	24	24	24	32
	250	.74	20	20	28	32	24	24	24	40	32	32	32	44	44	40
	271	.67	32	20	20		24	28	28	28	28	24	24	20	24	20
	276	.68	24	40	40	32		30	28	28	28	32	32	36	36	44
Average			21	24	28	24	25	24	23	27	26	28	25	29	29	34

* D = died.

TABLE XCV (*Continued*)

RESPIRATION RATE OF DOGS GASSED WITH CHLORPICRIN

Concentration 0.66–0.80 mgm. per liter (91–110 parts per million)

Hours after Exposure

13	*14*	*15*	*16*	*17*	*18*	*19*	*20*	*21*	*22*	*23*	*24–26*	*26–30*	*30–36*	*36–42*	*42–48*	
36		52		76		D										
32	48	40	40	48	44	60	60	60	60		64	D				
20	20	16	20	20	20	20	28	28			24		40			
80	40	52	48	28	40	16	40	24	20		24					D71
42	36	40	39	43	38	32	42	37	40		37		40			
24		16		24		16		16			18	20	24		40	
	44		48		46			40			44	28	32		36	
	60		28		56			44		48	66					
46		48			40		48		52							
40		28		36		36		36			42		38	46	30	
	40		32		36		48		48		46		48	52	60	
28	36	36	52	24	24	24	24	20			22					
44	52	48	48	72	72	72	68		30		32					
7	9	8	7	12	16	16			32			36	48	40	80	
28	30	20	26	32	32	28	26	28			36					
24	28	32	32	28	28	24	24				36					
20	20	24	24	24	28				26							
32	32	32	32	32	28	32	28	32			28					
40	36	40	40	36	28	24			32							
32	20	20	20	28	36	32	32	32	48		44					
36	40	24	28	32	24	44	52	44								
16	16	16	24	28	24	24	24				36					
28	32	48	48	52	40	44	40	36	40		36					
40	40	44	44	52	52	44	44		48							
28	36	32	24	20	24	32	28	28		28						
36	44	40	36		48		48		44		40					
31	34	31	30	33	36	33	38	32	40	38	37	42	38	46	49	

TABLE XCVI

Respiration Rate of Dogs Gassed with Chlorpicrin

Concentration 0.81–0.95 mgm. per liter (111–131 parts per million)

				Hours after Exposure												
	Dog No.	*Conc.*	*Normal*	*−1*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*
Deaths																
	210	.95	20	12	24	30	24		D*							
	12	.90	30	30	24	32	12		32		D					
	194	.90	16		24	16			16	17	16D					
	209	.91	20	8	6	10	32	24		8	8	D				
	63	.95	36	16		20	24			24	24		20	20		D
	77	.94	40	22			20	28		28	36		30			
	62	.93	40	16	20		20	20	20		16	24		16	20	
	218	.83	18	10	12	8	14	12	32	24	40	44	36	32	24	36
	189	.89	16	16	24	18		18		17	17	18		40		36
	217	.89	20	30	24	24	24	34	32	32	28	28	36	24	24	24
	207	.92	16		18	12	16	16	30	24	24	28	32	24	32	36
	215	.85	16	18	16	24	24	30	30	16	16	24	20	16	20	16
	196	.91	35	16		20		30	33	17	24	28	24	56	60	48
Average			25	18	19	22	21	23	28	21	22	28	28	28	30	33
Recoveries																
	17	.95	20	16	16	16		20		28	20		22		22	
	64	.95	48	20	20		28	24		20	14	14		12		14
	67	.88	28	44	22	20	18		20	28		28		24		22
	106	.87	14	16	20	32	34		44	36	56	44			48	56
	184	.92	18		18	22	16	16	16	55	40	50	40	20	20	24
	185	.93		8	10	12	20	16	18	18	15		16	28	32	28
	195	.88	24	10		22	24		25	24	24	24	24	22	24	32
	197	.93	18		18		16	17	8	8	9	24	32	34	38	32
	198	.87	22					12	16	8	12	8	16	20	20	19
	202	.83	16		16	16		16		18	16	18	11	24	32	20
	203	.88			12	30		14	10	14	23	12	12	14	24	28
	208	.91	12	16	24	20	18	16	24	32	28	24	24	36	36	24
Average			22	18	18	21	22	17	20	24	23	25	22	23	30	27

*D = died.

TABLE XCVI (*Continued*)

Respiration Rate of Dogs Gassed with Chlorpicrin

Concentration 0.81–0.95 mgm. per liter (111–131 parts per million)

Hours after Exposure

13	*14*	*15*	*16*	*17*	*18*	*19*	*20*	*21*	*22*	*23*	*24–26*	*26–30*	*30–36*	*36–42*	*42–48*	
							D									
20		24		32		38	D									
32	32	26	36	36	36	28	36	D								
		36	38			44					D					
32	28	24	26	22	20	24	32	28			44	20	60D			
32	40	36	32	34	42	40	40	40	60		50	90	60	D		
16	16	20	20	20	20	20	20	16			20	40	48	D		
46	44	44	44	32	32	32	32	28				24	22	28	25	D49
29	32	30	33	29	30	32	32	28	60		38	43	47	28	25	
28		28		28			30					32	32	44		
	20		24		22		20			28						
	40		32			28										
									32			48				
32	32	24	32	36	36							20				
48	44	36	28	32												
28		30	28	32	40	36										
46	44	40	36	48	48	50	54					60	60	80	87	
28	28	24	32	30	32	35	40									
22	34	32	34	34	28	40	36	34	34		30	32				
28	36	38	46	46	64	60	58	60		44	40					
32	28	40	38	38	42	42			18			24	22	20	20	
32	34	32	33	36	39	41	39	47	28	36	35	36	38	48	54	

TABLE XCVII

Respiration Rate of Dogs Gassed with Chlorpicrin

Concentration 0.96–1.10 mgm. per liter (132–151 parts per million)

Hours after Exposure

	Dog No.	*Conc.*	*Normal*	*½*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*
Deaths															
	52	1.06	40	32	40	12	D*								
	59	1.06	28	36	40		58	D							
	54	1.10	28		32	28	20		D						
	15	1.02	32	32	40	30	20	40	D						
	10	1.03	36	36	60	48	64	44	D						
	65	.98	24		20	34		32	12D						
	24	1.09	20	20	25	14		12	D						
	40	1.04	28	20	32	36	28	20		D					
	61	.97	24	24	20		32	32	12		D				
	57	1.07	24	48		48	44	40		40	48		D		
	25	1.11			32		32	28	30	28		40	D		
	14	.97	40	16	16	16	30	26	32	44		36		D	
	33	1.03	25		36	20	24	12	20	26		16	16		24
	44	1.03	20		16		16	20	16				36	28	36
	18	1.03	28	28	20		30		33	40		40		16	
	45	1.09	24	16		25	18	14				28	20	30	
Average			28	28	31	28	32	27	22	36		32	24	25	30
Delayed Deaths															
	50	1.05			24	24	20		20	18		16	16		36
	66	.96	24	20	20		24	24		36	24		16		22
	79	1.08	20	16		34	36		28		34				
	55	1.09	24	24	30	34		32	35		34		32		24
	51	1.09	20	20	24	20		20	24		22	20		29	24
	11	1.07	24		16	18	12	28		15		20		20	
Average			22	20	23	26	23	26	27	23	28	19	21	24	26
Recoveries															
	19	.97	20	12	22	24	18	20	14	14		17	24		24
	20	1.05	22	28	22	24	20	22	22		22	30		20	20
	21	1.06	20	56	60	36	42	32	32	38		42	52		48
	46	1.06		22	44	40	44	30			36		36	36	
	49	1.05		12	12	24			18	14		16		26	
	58	1.09	24	20	44	24		32	24	36		60	36		68
	75	1.00	24	24	8	20		16	20		24		14		13
Average			22	25	30	27	31	25	22	25	27	33	33	27	34

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* D = died.

TABLE XCVII (*Continued*)

Respiration Rate of Dogs Gassed with Chlorpicrin

Concentration 0.96–1.10 mgm. per liter (132–151 parts per million)

Hours after Exposure

12	*13*	*14*	*15*	*16*	*17*	*18*	*19*	*20*	*21*	*22*	*23*	*24–26*	*26–30*	*30–36*	*36–42*	*42–48*
	22		D													
	24		48		D											
34		30		36			36	D								
24		52		46		50		20	D							
29	23	41	48	41		50	36	20								
16		20		20		18		22		24		D				
	18		24		28			28					D			
													40	48	D	
	24		24		20		20					24	32		32D	
	32		32		26		36		32		40		44	92	66	
20		20		18		32			32					62	64	60D
18	25	20	27	19	25	25	28	25	32				39	50	54	
30		36		40		40		48		68		88		84	80	100
	20		20		20		24		24			36	36		40	60
	50		56		54		60		72			56				
20		44		28		32		60			40		80	32	36	
30		56		52		72			40			64		44	60	48
	50		50		56		56					28	40		40	
									20		22					
27	40	45	42	40	43	48	47	54	39		31	54	52	53	51	69

TABLE XCVIII

Respiration Rate of Dogs Gassed with Chlorpicrin

Concentration 1.11–1.25 mgm. per liter (153–172 parts per million)

				Hours after Exposure										
	Dog No.	*Conc.*	*Normal*	*½*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*
Deaths															
	30	1.21		15	24	24		30D*							
	26	1.16	18		32	22		32	28	D					
	22	1.15	20	20	40	14	13	16		20	D				
	60	1.18	24	16	26	28	36		36	48		24D			
	36	1.11	22	24	24	24		14	24		32		D		
	32	1.19	40	32	40		40	44	48	50		48	D		
	34	1.23	26	16	26	22	26	28	32		48	68		D	
	28	1.23	22	24	24	16	18	20		20	22		24	D	
	35	1.20	36		16	22	48		20	24		34		30	
	38	1.11	36		30	36	20	20	36	32	56		68	76	
	37	1.12	36	28		22	26	30	32	24		20	18		24
	41	1.15	24	18	16	28	16		16	28		16		24	
Average			28	21	27	23	27	26	30	31	39	35	37	43	24
Delayed Deaths															
	27	1.13	20	28	26		24	28	28	34		38	48		52
	48	1.11	18	18				24	24	36		32		40	
	47	1.22	18	12	6			13		28	34		36		40
	39	1.11	24	28	28	26	24	24	32	32		32	32		30
	23	1.16	20	16	12	16	26		24	32		40		36	
	56	1.12	24	20		28	20		28	32		36	46	50	
	16	1.14	32	29	20	22	40	44		42		60	54		28
Average			22	21	18	23	27	26	27	34	34	39	43	42	38
Recoveries															
	29	1.25	18		18	32	24		30	40		36		32	
	31	1.16	18	24	26	32	24	28	20	22	24		22	20	
	42	1.15	20		32	32		26	36		16		14		28
	53	1.15	24	28	24		28	16	18		20	16		22	
Average			20	26	28	32	25	23	26	31	20	26	18	25	28

* D = died.

TABLE XCVIII (*Continued*)

RESPIRATION RATE OF DOGS GASSED WITH CHLORPICRIN

Concentration 1.11–1.25 mgm. per liter (153–172 parts per million)

Hours after Exposure																	
12	*13*	*14*	*15*	*16*	*17*	*18*	*19*	*20*	*21*	*22*	*23*	*24–26*	*26–30*	*30–36*	*36–42*	*42–48*	
D																	
D																	
D																	
28		40		D													
28		40															
	48		48		32		60		44				D				
32		36		44			48				60		D				
	26		28		24			36				36	30	D			
	26		20		22		22		16			32	36	D			
32		40		32		44			36				40	D			
68		76		76		84		84						88	D		
	40		66		68		68			58				76		52	D53
44	35	51	40	51	37	64	49	60	32	58	60	34	35	82		52	
28		36		36		80					44			50		84	
32		40		50						44				52			
	26		28		24			24				18		20	22	20	
24		16		16		20		20		44			20	28	20		
28	26	31	28	37	24	50		22		44	44	18	20	38	21	52	

TABLE XCIX

Respiration Rate of Dogs Gassed with Chlorine

Concentration 800–900 parts per million (2.53–2.85 mgm. per liter)

Hours after Exposure

	Dog No.	*Conc.*	*Normal*	*–1*	*1–2*	*2–3*	*3–4*	*4–5*	*5–6*	*6–7*	*7–8*	*8–9*	*9–10*
Deaths													
	535	863	20	28	32	D*							
	531	893	20				18	18	20		D		
	534	967	12		18	20			32	28			32
	533	845	20		30	30	30	34	24		20		20
	532	846	20	40		40		40	40	40	40	40	
	528	857	18	56	60		44	40	40	36	32	28	24
	530	804	20	20	20	20	20	20	20	20		20	
Average			18	36	32	27	28	30	29	31	31	29	25
Recoveries													
	529	796	18	20	20	20	16	28	28	28	20	24	24

* D = died.

TABLE XCIX (*Continued*)

Respiration Rate of Dogs Gassed with Chlorine

Concentration 800–900 parts per million (2.53–2.85 mgm. per liter)

Hours after Exposure

10–11	*11–12*	*12–13*	*13–14*	*14–15*	*17–18*	*18–19*	*19–20*	*22–23*	*23–24*	*26–30*
					28	D				
	20								D	
56		56		40					D	
20							20	24	D	
12		12	16					D		
29										
						24		24		36

Data on Pulse Rate

Phosgene

TABLE C

Rate of Pulse after Phosgene Gassing

Animals that Die

Concentration of Phosgene 40–80 parts per million air (0.17–0.35 mgm. per liter)

Concentration	*50*	*47*	*50*	*46*	*46*	*50*	*42*	*52*	*52*	*54*	*54*	*55*	*52*	*55*
Dog	*P661*	*701*	*709*	*717*	*721*	*707*	*706*	*639*	*642*	*643*	*645*	*647*	*671*	*673*
Hours after Exposure														
Normal	100	108	104	112	100	106	108	76	92	80	66	132	108	88
1	48	80	76	62	72	56	62	64	72	60			76	
2	56		84	96	76	64		66	80	72	52	100	82	
3	64	86	80	84	80	64	92		72	80	56	108	96	92
4	92			88				72		92	72	124	92	98
5	78	100	76	92	124		92	64	80	96		136	90	88
6	64	112				84	130	84	76		72		92	
7	82							106	100	108				
8	88	108	88	108	104							132		122
9						84	144			120	96		92	
10		76						114	140			130		120
11	92		100	124		84	140			116	104		88	
12					104			112	112					132
13	103	104	108	116								128	100	
14							156		112	112				
15	88				88	80		100						96
16			108	106		84							84	
17		100										152		68
18	112				104					124			80	
19			118	104		92			140					
20	128	96						132					96	
21														
22	132	96	68	108								92	80	
23						108				136				
24–27	116	94		110					136	128		136	84	
28–30	107	92		108									84	
31–36														
37–42														
43–48													96	

TABLE C (*Continued*)

RATE OF PULSE AFTER PHOSGENE GASSING

Animals that Die

Concentration of Phosgene 40–80 parts per million air (0.17–0.35 mgm. per liter)

55	*54*	*59*	*56*	*60*	*58*	*72*	*73*	*79*	*73*	*78*	*76*	*77*	*76*	*74*	
674	*691*	*693*	*694*	*695*	*697*	*761*	*764*	*768*	*769*	*779*	*780*	*782*	*783*	*785*	*Average*
108	120	100	112	84	100	114	88	140	76	112	104	130	106	80	102
	80	60				96	72	76		64	64		68	42	68
	108				92	116	80	74	76	72				46	79
64			60	60	116				72			78	100		78
80			124	64		108	92	64	88	88	78			56	87
92	124	78			132	120	88	84				92	108	60	95
			132	70	148		128	96	96		100				94
108	128	80	140	100		128					116	96	100		107
	104	88			142	124	136	104	108					64	108
100			132	84								128	124		110
	88	88			132	140	132	116			128				117
120			120	96											108
	84				156	140	140								123
			88											76	104
	92	128						130				122	112		121
											76				88
						144	136								110
														104	107
		100	96					160							111
	124										108				116
						110	140								117
		120	140											136	132
								140							102
											116				120
		122				124	150				122			126	121
		132	140			112	136								114
			120												120
															96

DATA ON PULSE RATE

PHOSGENE

TABLE CI

RATE OF PULSE AFTER PHOSGENE GASSING

Animals that Live

Concentration of Phosgene 40–80 parts per million air (0.17–0.35 mgm. per liter)

Concentration	*50*	*45*	*43*	*50*	*45*	*47*	*47*	*45*	*45*	*46*	*50*	*49*	*51*	*53*
Dog	*P663*	*665*	*700*	*702*	*703*	*704*	*705*	*708*	*715*	*716*	*719*	*731*	*640*	*641*
Hours after Exposure														
Normal	88	72	112	92	96	104	80	96	84	160	112	40	68	68
1		100	64	80		68	52	74	66	104	60	84	76	112
2	56			76	92	72	52	84	72		70	72	80	116
3	50		56		108				84	106		80		120
4	56			88		84	88	80	66	108	78		88	88
5	54	98	80	116	128	100	80		80	112		88	80	112
6	58		84		128	90	72	128	80	106	112		68	148
7	64			100								108	88	136
8			92					128					98	156
9					124		100		100	132	140			
10	66		128	96		92						124		
11								140					84	100
12	67			124	132	100	102		116	124	160			132
13			128					116				96	92	
14	72				138	92	104							
15				104					104	92	148		90	124
16					128	90		132						
17	68	100	108	120			124		100	108		128		
18											144			
19	76				126	96		116	112				96	128
20			112				104			108				
21	80	140		120							175			
22			128		126	116	104	144						
23	86			112						140		132		
24–27	66	142	114	96	124	108	108		114	136	170		86	140
28–30	92		99						120	132			88	
31–36		142								124				
37–42														
43–48	96	80												

TABLE CI (*Continued*)

Rate of Pulse after Phosgene Gassing

Animals that Live

Concentration of Phosgene 40–80 parts per million air (0.17–0.35 mgm. per liter)

56	*55*	*51*	*55*	*58*	*53*	*59*	*51*	*52*	*73*	*75*	*76*	*79*	*76*	*76*	*72*	*Average*
644	*648*	*664*	*669*	*672*	*692*	*696*	*718*	*722*	*763*	*765*	*770*	*776*	*778*	*781*	*784*	
92	80	112	130	68	140	88	88	96	92	76	108	80	84	120	92	94
54		62	60	56	100		44	84	116	68	76	54	40	108	66	75
72	80	62		48	120		68	90	120		80	68				78
80	76	64		64		64	60	96		72	88				76	79
80	112			108		96	60		128	84	118		58	128		90
88	152	60		106	148		68	120	120	98		92			98	99
		64		92		98			148				80	128		99
104		68			164	92				96		108			88	101
	120				138		84	140	112		120		92	144		119
92			90	116		100				104		136			104	111
	148	68			120				152		104		108	140		112
86				120		82	72			112		164				107
		84			136			128	152							120
	132		130	140		100	80									113
80		76			136						128				128	105
								112		108			124	152		116
				140			92		130			104				117
	180	80	130		92	112										112
94				124		92		130			122				116	117
		92					102			140			130	170		115
				124	106			132	120			148				119
		88														121
	144			120				122			144				156	130
84		112				124	92	128		108			96	176		116
88	178	100		104	156	124	96	148	128	108	108	148			140	121
		84	120	96	124				116			124	112	172		114
																133
		96		104												94

TABLE CII

Pulse Rate after Chlorpicrin Gassing

Concentration of Chlorpicrin 70–89 parts per million air (0.51–0.65 mgm. per liter)

Hours after Exposure

	Dog No.	*Conc.*	*-1*	*1–2*	*2–3*	*3–4*	*4–5*	*5–6*	*6–7*	*7–8*	*8–9*	*9–10*	*10–11*	*11–12*	*12–13*	*13–14*
Deaths																
	277	.64	108	100		108	124	128	138	152	156	156	144	144	140	140
	261	.60		108	120	128	180	192	180	200	112	104	120	104	96	96
	8	.62	78	96	124	124	128	112	120	140	144		132		152	
	5	.62	44		56	56	52	48	64	96		96		92		96
Average			76	68	100	104	121	120	125	147	127	118	132	113	129	110
Recoveries																
	1	.64	52	68	70		100	96	144	100	132		100		104	
	4	.57	48	44	64		64	96	92	80	124		128		136	
	255		72		80	112	180	180	144	152	144	152	152	180	172	180
	256				100	120	116	120	112	116	112	128	132	132	124	140
	257	.56	64	120	136		140	144	140	120	128	136	168	148	136	132
	262	.62	82		84	80	104	100	128	88	120	132	160	176	152	100
	263	.58	50	80	100		120	140	134	128	136	136	148	124	188	180
	268	.65	64	64	64	96	100	116	124	108	120	120	128	136	140	144
	270	.59	52		58		60	80	76	80	96	100	104	96	104	112
	275	.62	76	100	120	116	120	124	132	168	188	168	180	180	180	180
	278	.64	80	84	100	100	120	112	128	128	112	108	112	108	108	84
	279	.64	80		108	100	112	140	144	152	168	180	168	172	160	172
	280	.61	44	64	100	84	86	84	88	72	88	92	96	80	92	80
	281	.65	64	60	122	132	128	140	144	144	140	144	168	160	160	
	282	.58		80	84		84	108	140		100	144	152	144	136	140
	285	.60	60	80	68		84	100	88	144	128	120	156	144	116	136
	289	.60	48	52	64	64	80	80	104	104	104	108	108	108	108	112
	290	.63	64	84	92	92	128	148	168	168	144	136	146	136	144	144
	295	.51	64	80	84	88	80	84	96	96	112	108		132		128
Average			63	76	89	99	105	115	122	119	126	130	139	139	137	135

* D = died.

TABLE CII (*Continued*)

Pulse Rate after Chlorpicrin Gassing

Concentration of Chlorpicrin 70–89 parts per million air (0.51–0.65 mgm. per liter)

Hours after Exposure

14–15	*15–16*	*16–17*	*17–18*	*18–19*	*19–20*	*20–21*	*21–22*	*22–23*	*23–24*	*24–26*	*26–30*	*30–36*	*36–42*	*42–48*
120D*			D											
160														
140		120		132		128		128		120	D			
	120		124		128			140		120		D		
140	120	120	124	132	128	128		134		120				
88		128		140		128		144	64	104	118	60	128	120
132		128		132		136				80	100			
160	160	176			172									
124	120	104			108									
132	132	176	168	144	152	160	168	160		132				
160	112	172			140									
180	200	180	188	180	180	180	180				140	120		120
128	140	120						120		120		80		
104	120	120	120	112	132	120	160	140		120				
172	200	196	180		140									
100	104		128		104		104	100						
172		160		168		164		160						
92		84		88	80		88							
136		128	136		120									
124	132	128	108	116	128	128	120					140		
152	160	160	152	160	160	160		152		88				80
128	100	106	104	92		98		100	110					88
156	144	144	156			135	100							
120		134	134		126	140								
135	140	141	143	133	134	141	131	134	87	107	119	100	128	102

TABLE CIII

Pulse Rate after Chlorpicrin Gassing

Concentration of Chlorpicrin 91–110 parts per million air (0.66–0.80 mgm. per liter)

Hours after Exposure

	Dog No.	*Conc.*	*Normal*	*½*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*
Deaths																
	247	.69	92		88	104	108	112	116	112	116	124	164	D*		
	225	.73	120		76	84		137	160	148	144	152	152	D		
	188	.75	92		68	64	70		68		66	54	69		124	
	236	.67	96		72	56		68	96	124	128	140	152	140	132	152
	216	.78	108		60	64	84	80	80	120	136	136	128	120	144	140
	251	.70	104	60	68	80		124	100	100		128	180	168	172	132
Average			102	60	72	75	87	104	103	121	108	122	141	142	143	141
Recoveries																
	2	.70	84	45	76		56	72	75	76	76		54		60	
	3	.66	124		63	68	80	112		100		102		126		124
	6	.75	108		68	94	84	80	64	100		84		86		96
	7	.80	120	72	72	68	112		112		116		140		130	
	9	.71	76	88	56	60	96	96	96	128	116		84		152	
	13	.76	124	48	76	120	120	132	128	168	168		108		108	108
	221	.77	116	68	100	120	116	120	152	200	204	168	180	172	164	184
	222	.78	120	68	80	80	80	84	112	104	96	117	128	128	132	128
	228	.75	112	36	68	76	100	128	124	160	124	120	144	148	140	140
	231	.68	116	96	100	92		92	96	106	108	134	116		132	140
	232	.80	124	60	68		88	112	113	112	124	120		120	124	118
	235	.78	96	56	84		120	120	124	152		152	136	152	154	152
	237	.68	128	68	68		128	176	164	160	160	120	156	168	192	176
	240	.75	120	72	68	80	92	88	92	104	108	132	148	132	140	152
	241	.80	92	64	92	96		80	80	96	92	158	132	120	92	120
	242	.72	128		104	108	124	144	152	144	148	140	144	172	180	168
	245	.75	80		56	72	80	100	80	88	76	80	80	88	96	80
	246	.71	144	52	76	80		112	116	136	128	180	164	164	168	140
	250	.74	104	84	107	136	136	144	172	172	164	188	180	200	180	160
	271	.67	132	52	52		56	80	80	92	88	96	96	96	108	120
	276	.68	84	88	100	100		84	80	120	140	120	128	128	144	156
Average			111	66	78	91	98	108	111	126	124	130	129	138	137	137

* D = died.

TABLE CIII (*Continued*)

Pulse Rate after Chlorpicrin Gassing

Concentration of Chlorpicrin 91–110 parts per million air (0.66–0.80 mgm. per liter)

Hours after Exposure

13	*14*	*15*	*16*	*17*	*18*	*19*	*20*	*21*	*22*	*23*	*24–26*	*26–30*	*30–36*	*36–42*	*42–48*	
88		76		88		D										
180	152	160	160	160	152	168	172	172	160		140	D				
138	120	120	124	124	124	128	132	132			120		148D			
144	164	176	180	180	168	168	160	176	180		176					D71+
140	145	133	155	138	148	155	155	160	170		145		148			
64		80		62		88		104			80	54	84		80	
	128		104		136			132				112	112		120	
	94		92		128			72		88	96					
136		130			128		188		160							
140		144		144		180		172			168		136	132	132	
	160		176		180		188		184		160		152	144	128	
160	168	168	164	168	168	168	172				154					
164	164	160	164	156	144	144	140		140		108					
154	154	160	154	156	156	154			180			208	170	164	144	
126	140	150	154	152	140	138	132	128			124					
134	118	146	138	148	152	152	152				124					
152	148	144	148	150	156				152							
176	180	176	152	160	152	160	160	168			168					
156	160	160	162	158	128	104			164							
112	104	120	112	120	104	96	88	96	96		132					
160	160	160	158	152	152	140	160				144					
96	96	96	144	140	136	140	100				116					
128	136	168	160	160	152	152	156	148	152		140					
164	168	196	180	192	216	164	188		184							
112	132	132	128	120	120	140	136	144		120						
180	172	140	144		144		144		136		140					
140	143	146	146	146	147	141	150	134	155	104	132	125	131	146	121	

TABLE CIV

Pulse Rate after Chlorpicrin Gassing

Concentration of Chlorpicrin 111–131 parts per million air (0.81–0.95 mgm. per liter)

Hours after Exposure

	Dog No.	*Conc.*	*Normal*	½	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*
Deaths																
	210	.95	132	68	144	140	144		D*							
	12	.90	90	60	64	56	66		72		D					
	194	.90	100		44	60		96	138	146	124D					
	209	.91	144	48	64	100	108	108		160	180	D				
	63	.95	74	60		80	128	160		176	194		216	212		D
	77	.94	136	110			148	180		188	168		174			
	62	.93	100	56	60		100	120	150		132	212		180	160	
	218	.83	88	48	60	60	120	100	120	140	152	216	212	216	200	200
	189	.89	62	56	56	72		90		114	120	176		134		108
	217	.89	128	84	100	120	132	136	152	160	156	148	144	180	160	168
	207	.92	92		42	48	44	64	40	48	52	58	48	96	84	48
	215	.85	64	40	48	52	60	84	92	108	132	124	140	148	160	140
	196	.91	96	60		60		56	80	72	90	94	108	120	126	126
Average			100	63	68	77	105	109	105	131	136	130	131	144	148	132
Recoveries																
	17	.95	96	56	76	100		128		120	98		132		124	
	64	.95	100	34	50		74	68		76	96	108		110		108
	67	.88	80	44	60	84	82		108	124		180		180		168
	106	.87	88	50	30	80	80		92	128	132	136			128	156
	184	.92	96		72	108	102	108	150	144	158	144	148	140	156	140
	185	.93	125	64	123	114	135	118	120	118	144	138	132	148	136	160
	195	.88	100	60		56	60		100	122	120	152	157	132	144	132
	197	.93	108		68		56	67	102	112	120	112	145	132	120	126
	198	.87	108					80	75	96	96	86	150	138	148	120
	202	.83	80		60	92		88		88	138	144	118	138	162	138
	203	.88	108		64	88		60	64	150	126	118	146	156	174	174
	208	.91	92	48	60	84	88	104	124	128	136	104	160	160	160	184
Average			98	51	66	89	85	91	104	117	124	120	135	143	145	146

* D = died.

TABLE CIV (*Continued*)

Pulse Rate after Chlorpicrin Gassing

Concentration of Chlorpicrin 111–131 parts per million air (0.81–0.95 mgm. per liter)

Hours after Exposure

13	*14*	*15*	*16*	*17*	*18*	*19*	*20*	*21*	*22*	*23*	*24–26*	*26–30*	*30–36*	*36–42*	*42–48*	
							D									
192		196		196		208	D									
188	188	172	210	164	176	194	196	D								
			132			68					D					
160	160	148	156	162	144	164	172	184			140	140	160D			
52	80	56	80	84	64	86	72	84	64		116	78	80	D		
160	136	156	120	124	144	132	132	124			128	148	160	D		
150	140	132	128	168	132	148	144	132				104	148	180	186	D49
127	141	143	138	149	130	143	143	131	64		128	117	137	180	186	
128		120		144			100					108	106	108		
	106		154		164		176			160						
	160		130		88											
									148			112				
152	164	128	140	128	128							120				
160	148	168	172	148							68					
168		156	172	164	164	144										
104	104	110	98	84	92	92	88					84	69	88	83	
124	140	130	172	164	160	164	130									
150	168	132	168	172	168	172	160	160	136		160	160				
130	164	160	172	180	176	212	176	152		164	164					
164	180	150	160	168	168	184			160			120	132	152	116	
135	160	140	153	150	145	161	140	156	148	162	131	117	102	116	99	

TABLE CV

Pulse Rate after Chlorpicrin Gassing

Concentration of Chlorpicrin 132–151 parts per million air (0.96–1.10 mgm. per liter)

Hours after Exposure

	Dog No.	*Conc.*	*Normal*	½	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Deaths														
	52	1.06	128	60	100	132	D*							
	59	1.06	92	90	120		124	D						
	54	1.10	80		100	160	168		D					
	15	1.02	100	70	104	120	140	160	D					
	10	1.03	96	48	52	60	76	70	D					
	65	.98	70		136	164		160	72D					
	24	1.09	114	92	68	120		180	D					
	40	1.04	72	56	92	112	108	160		D				
	61	.97	80	60	116		144	128	58		D			
	57	1.07	108	40		60	114	76		104	136		D	
	25	1.11	120		100		100	140	148	152		160	D	
	14	.97	120	54	76	70	120	116	104	132		100		D
	33	1.03	110		68	76	80	64	42	54		76	112	
	44	1.03	100		70		84	96	152				192	200
	18	1.03	128	40	48		80		132	90		140		60
	45	1.09	96	72		112	100	125				120	120	152
Average			101	62	90	108	111	123	101	106	136	119	141	137
Delayed Deaths														
	50	1.05			50	60	50		74	82		80	88	
	66	.96	74	65	96		96	104		108	116		124	
	79	1.08	92	56		116	128		176		172			
	55	1.09	96	60	76	92		90	108		96		120	
	51	1.09	100	64	140	116		144	152		150	192		136
	11	1.07	72		42	60		64	52	112		136		180
Average			87	61	81	89	91	100	112	101	133	136	111	158
Recoveries														
	19	.97	104		94	104	112	84	92	122		128	148	
	20	1.05	88	48	52	68	88	88	104		120	132		156
	21	1.06	104	44	56	68	64	64	84		100	84	88	
	46	1.06		50	64	76	76	76			92		92	104
	49	1.05		64	84	92			100	128		120		140
	58	1.09	92	56	60	70		68	64	64		112	128	
	75	1.00	60	48	56	96		114	152		168		144	
Average			89	52	67	83	85	82	99	104	120	115	120	133

* D = died.

TABLE CV (*Continued*)

Pulse Rate after Chlorpicrin Gassing

Concentration of Chlorpicrin 131–151 parts per million air (0.96–1.10 mgm. per liter)

Hours after Exposure

11	*12*	*13*	*14*	*15*	*16*	*17*	*18*	*19*	*20*	*21*	*22*	*23*	*24–26*	*26–30*	*30–36*	*36–42*	*42–48*
104		112		D													
216		200		140		D											
	160		164		164			164	D								
	132		128		124		124		32	D							
160	146	156	146	140	144		124	164	32								
108	100		136		120		116				92		D				
128		136		140		72								D			
														196	176	D	
88		108		128		106		116					100	112		84D	
130		172		160		164		180		92		148		184	144	152	
	160		152		176		176			180					110	116	124D
113	130	139	144	143	148	114	146	148		136	92	148	100	164	143	117	
168	140		160		128		120		128		140		144		118	112	120
128		164		144		160		140		136			132	116		124	112
84		88		84		76		76		88			88				
	96		92		104		94		100			84		100	112	108	
	152		128		112		64			112			116		100	136	97
136		140		120		104		108					102	92		124	
160										156		152					
155	129	131	127	116	114	113	93	108	114	123	140	118	116	103	110	123	109

TABLE CVI

Pulse Rate after Chlorpicrin Gassing

Concentration of Chlorpicrin 153–172 parts per million air (1.11–1.25 mgm. per liter)

Hours after Exposure

	Dog No.	*Conc.*	*Normal*	*½*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*
Deaths															
	30	1.21	120	46	118	128		176D*							
	26	1.16	108		64	128		140	160	D					
	22	1.15	92	40	80	104	76	116		104	D				
	60	1.18	80	34	63	92	116		180	180		204D			
	36	1.11	100	90	104	124		136	176		176		D		
	32	1.19	102	64	100		120	116	156	160		160	D		
	34	1.23	112	60	92	108	120	120	136		156	132		D	
	28	1.23	80	48	64	80	52	96		132	164		168	D	
	35	1.20	66		70	92	100		128	128		124		152	
	38	1.11	132		44	64	80	52	92	80	80		89	120	
	37	1.12	88	60		92	156	108	88	76		150	132		160
	41	1.15	144	60	68	88	120		144	160		170		168	
Average			102	56	77	100	104	118	140	127	144	157	130	150	160
Delayed Deaths															
	27	1.13	108	56	100		110	128	112	136		156	144		148
	48	1.11	132	108				168	164	162		168		156	
	47	1.22	84	36	56			128		152	148		156		148
	39	1.11	120	48	48	60	56	76	68	96		128	112		108
	23	1.16	112	46	52	64	82		104	98		108		100	
	56	1.12	90	64		80	112		130	128		160	164	168	
	16	1.14	104	71	90	100	100	104		104		120	128		108
Average			107	61	69	76	92	121	113	125	148	140	141	141	128
Recoveries															
	29	1.25	84		60	84	92		96	108		112		104	
	31	1.16	88	60	48	48	72	50	104	100	176		180	176	
	42	1.15	76		90	122		144	144		160		170		184
	53	1.15	112	62	76		72	82	84		60	60		80	
Average			90	61	68	85	79	92	107	104	132	86	175	120	184

* D = died.

TABLE CVI (*Continued*)

Pulse Rate after Chlorpicrin Gassing

Concentration of Chlorpicrin 153–172 parts per million air (1.11–1.25 mgm. per liter)

Hours after Exposure

12	*13*	*14*	*15*	*16*	*17*	*18*	*19*	*20*	*21*	*22*	*23*	*24 26*	*26–30*	*30–36*	*36–42*	*42–48*	
D																	
D																	
D																	
180		160		D													
180		160															
	156		148		136		144		154				D				
160		200		140			96				62		D				
	148		176		80			140				66	112	D			
	140		140		160		164		40			72	84	D			
132		132		124		128			124				130	D			
168		172		148		152		132				126		160	D		
	116		156		136		164			128				142		120	D53
153	140	168	155	137	128	140	142	136	106	128	62	88	109	151		120	
94		94		96		92					80			92		60	
172		170		170						168				148			
	180		172		168			150				164		152	111	120	
64		84		76		88		90		160			142	136	132		
110	180	113	172	114	168	85		120		164	80	164	142	132	121	90	

TABLE CVII

Pulse Rate after Chlorine Gassing

Concentration 800–900 parts per million (2.53–2.85 mgm. per liter)

				Hours after Exposure								
	Dog No.	*Conc.*	*Normal*	*1*	*1–2*	*2–3*	*3–4*	*4–5*	*5–6*	*6–7*	*7–8*	*8–9*
Deaths												
	535	863	96	74	80	D*						
	531	893	120				100	140	140		D	
	534	967	108		84	132			120	112		
	533	845	108		160	160	160	160	180		156	
	532	846	144	84		120		160	160	156	140	130
	528	857	100	60	68	80		112	144	108	84	72
	530	804	120	160	168	168	170	170	168	168		132
Average			114	94	112	132	110	148	152	136	126	111
Recoveries												
	529	796	72	48	48	48	48	92	120	140	160	160

* D = died.

TABLE CVII (*Continued*)

Pulse Rate after Chlorine Gassing

Concentration 800–900 parts per million (2.53–2.85 mgm. per liter)

Hours after Exposure

9–10	*10–11*	*11–12*	*12–13*	*13–14*	*14–15*	*17–18*	*18–19*	*19–20*	*22–23*	*23–24*	*30–36*
112						110	D				
148		180								D	
	100		116		144					D	
64	48							48	44	D	
	136		124	120					D		
104	94										
148									160		160

TABLE CVIII

Temperature Changes of Dogs Gassed with Phosgene

Animals that Recover

Concentration of Phosgene 40–80 parts per million air (0.17–0.35 mgm. per liter)

Concentration	*50*	*45*	*43*	*50*	*45*	*47*	*47*	*45*	*45*	*46*	*50*	*49*	*51*	*53*
	P663	*665*	*700*	*702*	*703*	*704*	*705*	*708*	*715*	*716*	*719*	*731*	*640*	*641*
Hours after Exposure														
Normal	38.4	38.8	39.1	39.0	38.6	38.7	38.6	39.6	39.6	39.4	39.0	39.5	39.2	39.1
1		38.3	38.4	37.9		37.4	37.4	38.4	38.8	38.3	38.5	36.4	38.1	39.0
2	37.7			38.2	39.1	38.2	38.1	38.8	38.4		38.8	36.5	38.0	38.8
3	38.4		38.5		39.4				38.6	38.6		38.1		
4	38.6			39.1		38.6	38.5	39.2	39.4	39.2			38.2	39.3
5	39.0	38.2	38.7	39.6	39.6	38.8	38.8		39.2	39.5		38.7	39.0	39.5
6	38.6		39.0		39.3	39.0	38.9	39.6	39.7	39.4	39.7		38.5	39.2
7	39.0			39.3								38.4	38.0	39.5
8			39.1					39.5					39.0	39.0
9					38.7		38.4		39.8	39.3	39.7			
10	39.1		38.9	39.3		39.0						38.1		
11								39.2					38.3	39.0
12	39.1			39.3	38.6	38.9	38.6		39.2	39.4	39.1			38.4
13			39.0					39.2				37.7	38.5	
14	39.1				38.6	38.5	38.4							
15				39.4					39.2	39.1	38.8		38.8	38.3
16					38.2	38.3		38.9						
17	39.1	39.1	38.6	39.1			38.2		38.0	39.1		36.2		
18											38.8			
19	38.6					37.7		38.9				35.3	38.8	37.5
20			38.1				38.3			38.8				
21	38.9	38.5		38.8							38.8			
22			37.8		38.8	37.9	38.6	39.1	38.3	38.5				
23	38.7			38.7								34.6		
24–25		39.3	38.0		38.0				38.6	38.4	38.6		38.4	37.6
26–27	38.5		38.0	38.5		38.0	38.6			38.6		35.8	38.8	38.1
28–29									38.9	38.8				
30–31	38.6													

TABLE CVIII (*Continued*)

Temperature Changes of Dogs Gassed with Phosgene

Animals that Recover

Concentration of Phosgene 40–80 parts per million air (0.17–0.35 mgm. per liter)

56	*55*	*51*	*55*	*58*	*53*	*59*	*51*	*52*	*73*	*75*	*76*	*79*	*76*	*76*	*72*	*Average*
644	*648*	*664*	*669*	*672*	*692*	*696*	*718*	*722*	*763*	*765*	*770*	*776*	*778*	*781*	*784*	
38.7	38.8	38.8	38.5	39.2	39.1	38.2	39.0	39.4	38.8	38.9		38.8	39.2	39.3	39.2	38.9
38.2		38.0	37.2	38.8	37.6			37.4	38.5	37.6	37.7	37.3	37.2	38.6	38.2	38.0
38.1	39.2	38.0		38.7	39.2		38.1	38.0	38.6		38.6	37.3	37.2		38.6	38.2
38.9	39.3	38.0		38.8		38.0	38.4	38.2		38.0	39.2					38.4
39.2	39.6			39.0		39.2	39.2		39.0	38.5	39.6		38.4	38.9	38.7	38.9
39.6	39.8	38.2		39.2	39.1		39.4	38.4	39.3	38.8		38.2				38.9
		38.3		39.2	39.2	39.3			39.3		39.6		38.8		38.8	39.1
39.6		38.4				39.4			39.2	39.0		38.6		38.8		38.9
	40.2				39.4		39.6	38.5			39.4		38.8		38.3	39.0
39.6				39.2		39.3			39.0	39.0		38.6				39.1
	40.1	38.6			38.9						39.0		38.8	39.0		38.9
39.2				39.1		39.2	39.3		39.1	39.5		38.8				39.0
		38.6	39.1		39.0			37.6								38.8
	40.0			39.1		38.7									38.0	37.5
39.1		38.4			39.0		39.2				38.5					38.7
								36.5	38.4	39.3			38.1	38.4		38.5
			38.2	39.1								38.6				38.5
	40.2	38.5				38.2	38.0								37.8	38.4
39.2				38.9	38.5			36.4			39.5					38.5
		38.2							38.4	39.3			37.9	38.3		38.0
				38.8		37.7	38.4	34.4				38.8				37.9
		38.6			38.5			35.4							37.6	38.1
	39.1			39.0							37.2					38.4
38.7		38.4				37.8				38.8				38.5		38.0
38.5	38.7			38.9	38.4		38.9	35.7	38.7			38.7	38.2			38.2
		38.3				38.1	38.8	35.9		38.8	37.8				38.7	38.0
			38.9	39.0	38.9				38.7			38.6	38.1	38.4		38.7
		38.4														38.5

TABLE CIX

Temperature Changes of Dogs Gassed with Phosgene

Animals that Die

Concentration of Phosgene 40–80 parts per million air (0.17–0.35 mgm. per liter)

Concentration	*50*	*47*	*50*	*46*	*46*	*50*	*42*	*52*	*52*	*54*	*54*	*55*	*53*	*52*
	P661	*701*	*709*	*717*	*721*	*707*	*706*	*639*	*642*	*643*	*645*	*647*	*662*	*671*
Hours after Exposure														
Normal	38.9	38.8	38.5	39.1	39.0	39.8	40.1	38.9	39.2	39.7	38.9	40.4	39.2	39.4
1	38.8	38.4	38.2	37.7	38.8	37.3	38.8	38.5	37.9	38.5		40.0		38.7
2	38.7		38.0	39.0	38.7	38.0		39.1	37.8	38.4	38.7	39.9	39.0	38.7
3	39.1	38.9	38.9	39.1	38.8	38.6	38.4		38.2	39.2	39.0		39.2	39.1
4	39.4			38.9				39.6		39.6	39.0	40.0	39.3	
5	39.6	38.9		39.1	39.3		38.6	39.6	38.7	40.0	39.5		39.5	39.4
6	39.7	39.1	39.1			39.2	39.1	39.5	38.8			40.0	39.7	39.4
7	39.7									40.0			39.4	39.2
8	39.5	38.8	38.6	37.8	39.5	39.2		39.2	38.8		39.5			
9			38.6				39.0					39.6		39.7
10								38.5	39.1	40.1	38.5		39.3	
11	39.2	38.8		38.1		38.5	38.7			39.9		39.2		39.3
12			38.1		39.1			38.2	38.5				38.9	
13	38.1	38.6				38.3				39.4		39.2		39.0
14				36.9			38.1	38.2	37.7				38.9	
15	37.2				38.4									
16		38.5	36.6			37.8							38.5	38.9
17				34.5								38.4		
18	36.3	38.8			36.0			38.6	38.5	39.1				38.8
19			36.7			37.7							38.4	
20	37.3			32.4										38.7
21		38.6												
22	36.5		36.1	33.2		38.1						37.7	38.4	38.4
23										39.3				
24-25	36.5	38.5		31.8					35.1	39.0		37.3	38.5	
26-27	37.2	38.1		34.2					35.0				38.4	38.5
28-29				33.2										38.2
30-31	37.4												38.8	

TABLE CIX (*Continued*)

Temperature Changes of Dogs Gassed with Phosgene

Animals that Die

Concentration of Phosgene 40–80 parts per million air (0.17–0.35 mgm. per liter)

55	*55*	*54*	*59*	*56*	*60*	*58*	*72*	*73*	*79*	*73*	*78*	*76*	*77*	*76*	*74*	*Average*
673	*674*	*691*	*693*	*694*	*695*	*697*	*761*	*764*	*768*	*769*	*779*	*780*	*782*	*783*	*785*	
40.6	40.1	38.5	39.0	39.1	38.4	39.9	39.0	39.5	39.1	39.3	39.4	39.1	40.4	38.8	38.8	39.2
		37.9	37.3				38.0	37.9	38.0	38.8	38.8	37.8	38.2	38.7	37.6	38.2
		38.7					37.8	38.0	38.1	38.8	38.8				37.4	38.4
39.0	39.2			38.0					38.9	38.9			37.6	38.9		38.7
39.1	39.2		39.0		39.0	39.2	38.2	38.2	39.4	39.3		37.9			38.6	37.9
39.1	39.2	40.4		38.6		39.7	38.9	39.2			38.2		38.0	38.8		39.1
			39.2	39.0	38.6	40.5		40.0	39.2	39.4		38.8			37.9	39.2
	39.0	40.0		39.0	38.2	40.5	39.1					39.4	38.4	39.0		39.3
38.9		39.8	39.4			40.4	39.0	40.0	39.0	38.2					38.1	39.0
	38.3			38.6	36.2								38.3	38.6		38.4
38.9		38.7	39.0			38.0	39.0	39.6	38.4			38.5				38.8
	38.6			38.4	34.2											38.4
38.1		37.4	39.4			36.3	39.0	39.6								38.4
				38.0								38.0			37.4	38.4
		36.5	38.5						37.1				37.2	38.3		37.7
37.0																37.5
							38.5	39.3								38.3
35.2				37.8								37.8			36.8	36.7
		36.1	36.6						37.0							37.3
																37.6
							38.4	39.1								35.6
			35.8	37.2											36.2	36.9
									36.1							36.8
												36.0				37.6
			36.1	37.3			37.6	38.9								36.0
															37.2	36.8
			37.2	35.2			38.4	39.4				38.0				37.0
																38.1

TABLE CX

Temperature Changes of Dogs Gassed with Chlorpicrin

Concentration of Chlorpicrin 70–89 parts per million air (0.51–0.65 mgm. per liter)

Hours after Exposure

	Dog No.	*Conc.*	*-1*	*1-2*	*2-3*	*3-4*	*4-5*	*5-6*	*6-7*	*7-8*	*8-9*	*9-10*	*10-11*	*11-12*	*12-13*	*13-14*
Deaths																
	8	.62	38.2	38.6	37.9	37.7	37.8	36.5	36.5	36.1	36.4		39.6		37.8	
	5	.62	38.0		38.5	38.8	39.1	39.0	38.5	39.2		38.9		38.7		38.1
Recoveries																
	1	.64	37.9	38.3	38.5		38.9	38.4	38.6	38.7	38.2		38.0		38.4	
	4	.57	37.2	37.4	37.8		38.6	38.7	37.6	37.8	38.7		39.2		38.9	
	255		37.4		38.3	38.7	39.0	39.1	39.1	39.1	39.4	39.3	39.1	39.2	39.0	39.0
	256				39.2	39.5	39.5	39.4	39.3	39.2	39.0	39.4	39.1	39.0	39.0	38.7
	257	.56	37.5	38.4	39.2		39.1	39.4	39.4	39.4	39.7	39.5	39.4	39.3	39.5	39.7
	262	.62	38.1	38.0	38.4	38.8	38.5	39.1	39.2	39.6	39.1	39.1	38.9	38.8	38.7	38.4
	263	.58	37.5	38.1	38.6		38.4	38.7	38.6	38.6	38.3	38.6	38.3	38.3	38.0	38.0
	268	.65	37.8	38.1	38.2	38.6	38.8	38.8	38.2	38.8	38.8	38.8	38.8	38.7	38.6	38.5
	270	.59	36.0	36.4	37.8		37.8	38.4	37.9	37.6	38.2	38.4	38.2	38.5	39.2	38.1
	275	.62	39.2	39.4	39.0	40.3	40.2	40.2	40.2	39.1	38.9	40.0	39.8	39.7	39.7	39.7
	278	.64	37.7	36.5	38.7	39.0	38.8	38.8	38.7	38.9	38.6	38.7	38.7	38.7	38.7	38.5
	279	.64	38.0		37.6	37.8	37.5	38.2	38.3	38.1	38.2	37.7	37.9	37.6	38.2	38.4
	280	.61	38.0	36.6	36.8	37.0	37.5	38.3	38.6	38.5	38.5	38.4	38.2	38.1	38.2	37.9
	281	.65	38.4	38.4	39.0	38.8	39.0	39.0	39.2	38.8	39.0	39.3	39.0	39.4	39.2	
	282	.58		38.5	38.4		38.4	38.4	38.7	38.2	38.7	38.9	38.7	38.7	38.9	38.9
	285	.60	38.2	38.4	38.2		39.2	39.2	39.0	39.6	39.4	39.5	39.2	39.3	39.1	39.1
	289	.60	37.8	37.5	37.4	37.1	37.7	38.2	38.4	38.6	38.8	38.8	38.6	38.4	38.4	38.4
	290	63	38.1	38.1	38.4	38.7	38.6	38.5	38.2	38.2	38.3	38.2	38.3	38.2	38.0	38.0
	295	.51	39.4	38.5	38.9	39.0	39.0	39.0	39.4	39.2	39.3	39.0		39.1		39.0
Average			37.9	37.9	38.1	38.6	38.7	38.8	38.8	38.7	38.8	38.9	38.7	38.7	38.7	38.7

* D = died.

TABLE CX (*Continued*)

TEMPERATURE CHANGES OF DOGS GASSED WITH CHLORPICRIN

Concentration of Chlorpicrin 70–89 parts per million air (0.51–0.65 mgm. per liter)

Hours after Exposure

14–15	*15–16*	*16–17*	*17–18*	*18–19*	*19–20*	*20–21*	*21–22*	*22–23*	*23–24*	*24–26*	*26–30*	*30–36*	*36–42*	*42–48*
36.5		37.2		35.6		35.2		35.3		34.3	D*			
	38.1		37.9		38.7			38.1		38.3		D		
38.2		38.5		38.5		38.4		38.7		39.0	38.5	38.3	38.9	38.8
38.5		38.7		38.9		38.2			38.4	38.1	38.6			
39.1	38.8	39.0		39.1										
38.8	38.8	38.9			38.4									
39.7	39.6	38.4	39.3	39.2	39.3	39.2	39.1	39.0		39.2				
38.5	38.4	38.5			38.8									
38.0	38.5	38.5	38.3	38.4	38.3						37.9	37.8		37.8
38.7								37.8		37.7		38.2		
38.1	38.3	37.8	37.9	38.0	38.1	38.2	38.3	38.3		38.4				
39.4	39.3	39.4	39.6		39.4									
38.5	38.5		38.4	38.7		38.2		38.7						
38.3		38.2		38.0		38.1		38.0						
38.0		37.9		37.7	37.5		37.4							
39.2		39.0	39.0		39.0									
38.9	38.7	38.7	38.9	38.8	38.8	38.6	38.5					38.1		
38.9	38.7	38.5	38.6	38.5	38.6	38.7		38.7		38.5				38.6
38.2	38.0	38.3	38.2	38.1		38.1		38.4	38.4					38.0
38.2	38.0	38.2	38.2			38.2	38.4							
39.0		39.0	39.1		39.1	39.4								
38.7	38.6	38.6	38.7	38.5	38.6	38.5	38.3	38.5	38.4	38.5	38.3	38.1	38.9	38.3

TABLE CXI

Temperature Changes of Dogs Gassed with Chlorpicrin

Concentration of Chlorpicrin 91–110 parts per million air (0.66–0.80 mgm. per liter)

Hours after Exposure

	Dog No.	*Conc.*	*Normal*	½	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*
Deaths															
	247	.69	38.4		38.6	38.4	38.1	37.4	36.6	36.9		36.8	37.4	D*	
	225	.73	39.1		37.1	36.0		35.4	35.0	35.4	35.2	35.4	35.6	D	
	188	.75	38.8		38.0	38.0	38.3		38.3		38.5	38.3	38.3		38.1
	236	.67	39.2		38.5	38.9		38.7	38.5	38.6	38.9	38.7	38.8	38.4	38.7
	216	.78	38.7		36.9	36.9	37.7	37.8	37.4	38.0	37.8	37.2	37.2	37.7	37.3
	251	.70	39.1	37.7	37.4	36.9		37.6	38.0	37.8		38.2	37.9	37.8	37.7
Average			38.9	37.7	37.7	37.5	38.0	37.4	37.3	37.3	37.6	37.4	37.5	37.9	37.9
Recoveries															
	2	.70	38.6	38.0	37.9		38.0	38.0	38.3	38.3	38.2		38.3		37.2
	3	.66	38.2		37.8	39.2	38.3	38.5		38.9		38.6		37.9	
	6	.75			38.5	37.7	38.4	37.9	38.5	38.5		38.6		38.5	
	7	.80	39.6	37.8	38.0	37.7	38.5		38.4		38.9		38.2		38.3
	9	.71	39.1	38.4	38.0	38.1	38.5	38.2	38.8	38.8	39.1		39.5		39.6
	13	.76	39.5	37.5	36.9	37.8	37.8	38.5	38.9	38.9	38.6		37.8		38.0
	221	.77	38.7	37.3	37.4	38.0	38.6	38.7	38.6	38.7	39.0	39.1	39.2	38.9	38.7
	222	.78	39.1	37.8	37.8	38.2	37.8	38.7	38.7	38.8	38.8	38.7	38.6	38.3	38.5
	228	.75	38.7	37.2	35.8	36.3	37.3	38.2	37.9	37.7	37.6	37.6	37.5	37.2	37.7
	231	.68	39.6	38.0	38.2	38.2		38.4	38.7	38.6	38.7	38.7	38.7		38.6
	232	.80	38.5	37.5	36.8		37.1	37.8	38.1	38.2	38.5	38.5		38.3	38.4
	235	.78	38.8	38.0	38.5		38.6	38.6	38.6	38.7		39.0	38.8	38.8	39.0
	237	.68	39.3	37.9	37.5		38.8	38.6	38.6	39.1	38.8	38.7	39.1	39.0	39.0
	240	.75	39.4	38.8	38.1	37.8	37.9	38.3	38.3	38.6	38.3	38.5	38.2	38.2	38.0
	241	.80	38.6	37.2	38.5			39.4	39.9	39.9	39.9	39.7	39.5	39.4	39.2
	242	.72	38.8		38.2		38.6	38.5	38.8	38.6	39.0	38.7	38.5	38.4	38.0
	245	.75	39.2		37.7	38.3	38.1	38.1	38.5	38.3	38.6	38.3	38.5	38.4	38.7
	246	.71	38.8	37.5	38.1	38.1		38.3	38.9	39.0	39.1	39.2	38.6	39.0	39.0
	250	.74	38.2	38.4	38.7	39.2	39.2	39.3	39.6	39.4	39.5	39.1	39.3	38.8	39.3
	271	.67	39.0	36.6	37.0		37.5	37.9	37.6	37.5	37.2	37.3	37.0	36.9	37.0
	276	.68	38.6	37.7	37.9	38.6		38.6	38.7	38.6	38.8	38.8	38.8	38.9	38.9
Average			38.9	37.7	37.8	38.1	38.2	38.4	38.7	38.7	38.7	38.7	38.5	38.4	38.5

* D = died.

TABLE CXI (*Continued*)

Temperature Changes of Dogs Gassed with Chlorpicrin

Concentration of Chlorpicrin 91–110 parts per million air (0.66–0.80 mgm. per liter)

Hours after Exposure																
12	*13*	*14*	*15*	*16*	*17*	*18*	*19*	*20*	*21*	*22*	*23*	*24–26*	*26–30*	*30–36*	*36–42*	*42–48*
	38.0		38.3		37.7		D									
39.0	38.9	38.6	38.8	38.8	38.8	38.8	38.8	38.8	38.7	38.7		38.8	D			
37.2	37.5	35.2	36.5	36.4	36.7	36.5	36.6	36.9	37.0			37.3		37.8D		
37.9	37.2	37.6	37.6	37.5	37.3	37.5	37.4	37.1	37.1	37.1		36.1				
38.0	37.9	37.1	37.8	37.6	37.6	37.6	37.6	37.6	37.6	37.9		37.4		37.8		
	37.5		37.2		37.9		37.4		38.0			38.5	38.0	38.2		38.4
38.4		37.9		38.3		38.0			38.3			37.8	37.8	38.1		37.7
38.6		38.5		38.6		38.7			38.5		38.6	38.5				
	37.2		38.2			38.2		38.8		38.8						
	39.1		39.0		38.9		38.4		38.8			38.8	40.0	38.9	39.6	39.6
37.4		37.7		36.7		37.2		37.7		37.7		39.1		39.4	39.4	38.6
38.8	38.7	38.9	39.2	38.9	39.0	39.0	39.0	38.8	38.7			38.6				
38.5	38.2	38.3	38.4	38.6	38.5	38.5	38.2	38.5		38.4		38.4				
38.3	38.4	37.7	38.3	38.5	38.2	38.7	38.8			38.6			38.8	39.2	39.2	38.9
38.4	38.7	38.6	38.7	38.7	38.7	38.8	38.7	38.9	38.7			38.9				
38.4	38.3	38.2	38.2	38.3	38.2	38.3	38.4	38.5				38.4				
39.0	38.6	38.5	38.6	38.9	38.7	38.5				38.2						
39.2	39.0	39.2	39.2	39.2	39.1	38.9	39.1	38.9	38.9			38.8				
37.8	37.7	37.5	37.4	37.5	37.2	37.8	37.7			37.6						
39.0	39.1	38.8	38.8	38.8	38.9	38.8	38.8	38.7	38.7	38.9		38.6				
38.0	38.0	38.3	38.3	38.3	38.3	38.2	38.1	38.0	38.0			37.6				
38.6	39.0	38.8	39.0	38.7	38.8	38.7	38.6	38.6				38.7				
38.9	39.1	39.2	39.3	39.2	39.3	39.3	39.1	39.2		39.2		38.8				
39.2	39.0	39.1	39.0	38.9	38.8	38.8	38.8	39.0		39.3						
36.8	36.9	36.7	37.2	36.5	36.4	36.0	35.8	36.0	36.0		36.0					
38.7	38.2	38.8	38.9	38.9		38.8		38.7		38.5		38.4				
38.5	38.4	38.4	38.5	38.4	38.4	38.3	38.3	38.3	38.3	38.5	37.3	38.5	38.7	38.7	39.4	38.6

TABLE CXII

Temperature Changes of Dogs Gassed with Chlorpicrin

Concentration of Chlorpicrin 111–131 parts per million air (0.81–0.95 mgm. per liter)

Hours after Exposure

	Dog No.	*Conc.*	*Normal*	½	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*
Deaths																
	210	.95	39.1	38.7	37.4	37.2	37.0		D*							
	12	.90	38.6	37.9	38.0	37.8	37.2		38.2		D					
	194	.90	38.2		36.8	36.8		35.2	35.2	35.8	35.4D					
	209	.91	38.3	37.1	36.5	36.7	37.3	37.2		37.1	38.5	D				
	63	.95	39.2	37.7		37.9	38.1	37.9		38.9	38.6		38.6	38.9		D
	77	.94	38.9	38.8			38.5	37.5		36.9	36.7		36.5			
	62	.93	39.0	37.9	37.9		38.0	37.8	37.7		38.0	38.6		38.5	38.5	
	218	.83	39.0	38.0	38.0	38.1	38.2	38.3	38.5	38.5	38.8	38.9	38.9	38.9	39.0	38.8
	189	.89	38.5	38.5	37.4	38.2		38.0		38.3	38.3	38.5		38.2		38.3
	217	.89	38.5	37.3	37.3	37.2	37.9	38.1	38.1	38.0	37.8	38.2	38.3	38.2	38.0	37.8
	207	.92	38.6		37.0	37.1	37.7	37.3	37.0	37.4	37.5	37.7	37.7	38.1	38.0	38.0
	215	.85	38.2	38.2	37.9	37.9	37.8	38.1	37.8	37.8	38.0	38.0	37.9	38.1	37.8	37.3
	196	.91	39.4	39.1		38.6		38.5	38.7	39.0	38.8	38.9	38.9	39.1	38.9	39.0
Average			38.7	38.2	37.4	37.6	37.8	37.6	37.6	37.8	37.8	38.4	38.1	38.5	38.4	38.2
Recoveries																
	17	.95	39.3	37.5	38.1	38.7		38.6		39.1	38.6		38.6		38.6	
	64	.95	39.5	38.3	37.5		37.5	37.7		37.9	37.5	37.4		37.8		37.4
	67	.88	37.9	37.4	37.1	36.8	37.0		37.0	37.0		36.9		37.0		37.3
	106	.87	39.2	37.2	38.0	38.3	38.7		39.1	39.3	39.6	39.3			39.1	38.8
	184	.92	38.6		38.0	38.5	38.6	38.9	38.5	38.8	38.9	38.9	38.8	38.7	38.8	38.9
	185	.93	39.7	38.5	38.3	38.9	39.3	39.3	38.8	38.9	38.9	38.9	38.6	38.2	38.3	38.1
	195	.88	38.6	36.9		36.5	37.4		38.5	38.7	38.7	38.2	38.2	38.1	37.5	37.5
	197	.93	38.2		36.8		37.4	38.1	38.2	38.1	38.2	38.3	38.3	38.8	38.4	38.0
	198	.87	38.8					38.3	38.8	38.8	38.7	38.6	38.3	38.3	38.6	38.5
	202	.83	38.6		35.9	36.9		37.3		37.7	37.8	37.8	37.2	37.2	37.2	37.3
	203	.88	38.9		37.3	37.5			38.5	38.6	38.2	38.4	38.5	38.5	38.6	38.1
	208	.91	39.1	38.2	38.1	38.1	38.7	38.8	39.1	38.9	38.3	38.5	38.9	38.8	38.8	38.9
Average			38.8	37.7	37.5	37.7	38.1	38.4	38.5	38.5	38.5	38.3	38.4	38.2	38.4	38.1

* D = died.

TABLE CXII (*Continued*)

Temperature Changes of Dogs Gassed with Chlorpicrin

Concentration of Chlorpicrin 111–131 parts per million air (0.81–0.95 mgm. per liter)

Hours after Exposure

13	*14*	*15*	*16*	*17*	*18*	*19*	*20*	*21*	*22*	*23*	*24–26*	*26–30*	*30–36*	*36–42*	*42–48*	
							D									
39.1		39.6		39.8		39.8	D									
39.1	39.0	38.9	38.7	38.8	38.8	38.7	38.3	D								
		38.2	38.3			38.5					D					
38.0	37.7	37.8	38.0	38.0	37.7	37.8	37.8	37.3			37.3	37.2	37.9D			
37.9	37.3	37.4	37.4	37.4	37.5	37.5	37.5	37.5	37.3		36.9	37.0	37.4	D		
37.5	37.3	37.5	37.8	37.8	37.8	37.8	37.7	37.8			37.7	37.9	37.7	D		
38.9	38.8	38.8	38.8	38.9	38.9	38.9	39.0	39.0				39.4	39.8	39.7	40.3	D49
38.4	38.0	38.3	38.1	38.4	38.1	38.4	38.1	38.0	37.3		37.3	38.0	38.2	39.7	40.3	
38.5		38.2		38.4			38.8					38.2	39.2	38.8		
	36.8		37.2		37.9		38.0			38.3						
	37.8		37.9			38.3										
										39.1		38.6				
38.8	38.7	38.7	38.6	38.6	38.7							38.9				
38.1	37.9	38.1	38.0	37.8							38.6					
37.3		38.0	37.8	37.5	38.1	37.9										
38.1	38.4	38.6	38.3	38.0	38.2	38.7	38.2					37.8	38.9	37.4	37.7	
38.6	38.4	38.4	39.0	38.7	38.7	38.8	38.9									
37.4	37.8	37.4	37.9	37.9	38.1	38.0	37.8	37.5	37.2		37.7	38.0				
38.9	38.0	37.7	38.6	37.5	38.3	38.3	38.1	38.3		38.0	38.2					
39.0	38.7	38.9	38.8	39.1	39.0	38.9			39.2			39.3	39.0	39.2	39.1	
38.3	38.1	38.2	38.2	38.1	38.4	38.4	38.3	37.9	38.2	38.4	38.1	38.4	39.0	38.1	38.4	

TABLE CXIII

Temperature Changes of Dogs Gassed with Chlorpicrin

Concentration of Chlorpicrin 132–151 parts per million air (0.96–1.10 mgm. per liter)

				Hours after Exposure										
	Dog No.	*Conc.*	*Normal*	*½*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*
Deaths															
	52	1.06	39.7	39.2	38.2	37.6	D*								
	59	1.06	38.9	39.1	38.9		39.2	D							
	54	1.10	39.5		38.8	38.6	38.6		D						
	15	1.02	39.5	37.5	37.4	37.4	37.1	36.5	D						
	10	1.03	37.9	37.4	37.0	36.4	35.9	35.4	D						
	65	.98	38.9		37.5	37.9		38.0	D						
	24	1.09	39.2	39.4	38.5	38.4		38.7	D						
	40	1.04	38.5	37.9	37.8	38.5	38.4	37.9		D					
	61	.97	39.0		38.1		38.2	38.6	37.9		D				
	57	1.07	39.0	38.3		37.0	37.5	35.2		36.6	36.2		D		
	25	1.11	39.2		36.6		37.4	37.5	37.3	36.7		37.0	D		
	14	.97	38.5	37.6	36.8	37.4	37.4	36.9	36.6	36.2		35.5		D	
	33	1.03	39.3		38.6	38.0	38.2	38.3	38.1	38.4		38.6	39.0		39.1
	44	1.03	40.0		38.6		38.7	39.5	39.2				38.2	38.6	38.7
	18	1.03	39.5	37.9	38.0		37.5		36.5	38.2		36.5		36.2	
	45	1.09	38.9	37.8		37.7	37.9	37.8				37.2	37.4	37.4	
Average			39.1	38.2	37.9	37.7	37.8	37.5	37.6	37.2	36.2	37.8	38.2	37.4	38.9
Delayed Deaths															
	50	1.05	38.3		38.8	38.0	38.4		38.3	38.3		38.1	38.1		38.1
	66	.96	40.0	37.2	37.0		37.7	37.8		37.4	37.2		37.3		37.4
	79	1.08		39.2		39.0	38.9		38.9		39.2				
	55	1.09	38.4	36.0	35.4	35.2		36.5	36.0		36.5		36.6		36.3
	51	1.09	39.0	37.6	37.6	38.0		38.5	38.3		38.3	38.1		38.0	38.0
	11	1.07	38.4		37.5	37.2	37.3	35.6		37.2		37.0		36.5	
Average			38.8	37.5	37.3	37.5	38.1	37.1	37.8	37.9	37.8	37.7	37.3	37.3	37.4
Recoveries															
	19	.97	39.4	37.4	36.4	37.0	37.7	37.8	38.4	38.5		38.3	38.4		38.1
	20	1.05	39.7	36.8	37.6	37.7	38.0	37.4	38.0		37.6	37.3		37.0	37.6
	21	1.06	39.6	38.1	36.5	36.6	36.7	37.4	37.6	37.2		37.9	38.0		37.6
	46	1.06		39.0	38.5	37.8	38.5	38.3			38.6		38.4	38.4	
	49	1.05		38.5	38.1	38.3			38.4	38.2		38.2		37.9	
	58	1.09	39.1	38.7	38.3	38.6		39.6	38.9	38.8		38.6	38.8		38.6
	75	1.00	38.9	38.0	36.8	38.0		38.5	38.7		38.7		38.6		38.7
Average			39.3	38.1	37.5	37.7	37.7	38.1	38.3	38.2	38.3	38.1	38.4	37.7	38.1

* D = died.

TABLE CXIII (*Continued*)

TEMPERATURE CHANGES OF DOGS GASSED WITH CHLORPICRIN

Concentration of Chlorpicrin 132–151 parts per million air (0.96–1.10 mgm. per liter)

Hours after Exposure																
12	*13*	*14*	*15*	*16*	*17*	*18*	*19*	*20*	*21*	*22*	*23*	*24-26*	*26-30*	*30-36*	*36-42*	*42-48*
	39.2		D													
	38.8		37.8		D											
35.3		34.3					35.6	D								
37.2		37.2		36.4		36.5		36.0	D							
36.3	39.0	35.7														
38.3		38.2		38.2		38.9		38.7		38.8						
	37.3		37.3		37.8			37.5					D			
													39.1	38.5	D	
	35.9		36.8		37.8		37.0					38.2	38.4		36.1D	
	38.3		38.2		38.7		38.1		38.3		38.2	38.7		38.5	37.4	
37.2		36.4		36.4		37.9			36.1				37.5	36.7	37.6	37.0D
37.7	37.2	37.3	37.4	37.3	38.1	38.4	37.6		37.2			38.5	38.3	37.9	37.0	
38.1		37.6		37.9		38.0		38.1		38.2		38.5		38.2	37.8	37.5
	37.5		37.2		37.3		37.7		37.5			38.4	36.7		38.6	38.7
	37.6		37.8		37.9		38.1		38.6			38.8				
38.5		38.4		38.3		38.4		38.5			38.6		38.9	39.7	38.9	
38.5		38.5		38.5		38.4			38.2			38.7		38.3	38.1	38.6
	38.5		38.7		38.6		38.6					39.1	40.6		40.0	
									38.0		38.1					
38.3	37.9	37.8	37.9	38.2	37.9	38.3	38.1	38.2	38.1	38.2	38.4	38.7	38.7	38.7	38.7	38.2

TABLE CXIV

Temperature Changes of Dogs Gassed with Chlorpicrin

Concentration of Chlorpicrin 153–172 parts per million air (1.11–1.25 mgm. per liter)

				Hours after Exposure											
	Dog No.	*Conc.*	*Normal*	*½*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*
Deaths															
	30	1.21	39.4	39.4	37.9	37.8		37.8D*							
	26	1.16	39.0		38.6	37.7		37.7	36.7	D					
	22	1.15	39.9	38.2	38.1	38.6	39.0	39.1		37.1	D				
	60	1.18	39.0	38.7	37.3	36.6	36.4		35.9	37.6		36.1D			
	36	1.11	39.2	38.6	38.4	38.1		38.5	38.8		37.7		D		
	32	1.19	38.7	39.0	38.6		38.7	38.6	38.6	38.8		39.2	D		
	34	1.23	38.5	39.2	38.0	37.6	37.9	37.9	37.8		38.0	38.6		D	
	28	1.23	39.2	39.1	36.5	39.5	39.5	39.2		38.6	38.1		38.2	D	
	35	1.20	38.3		38.5	38.4	38.4		38.3	38.0		37.5		38.0	
	38	1.11	39.8		38.6	38.5	38.7	39.2	39.6	39.4	38.7		38.0	38.2	
	37	1.12	39.2	38.0		38.0	38.0	38.0	38.5	38.2		37.2	37.4		37.8
	41	1.15	39.4	38.8	37.9	38.5	38.6		38.2	37.2		38.0		38.5	
Average			39.1	38.8	38.0	38.1	38.4	38.4	38.0	38.1	38.1	37.7	37.9	38.2	37.8
Delayed Deaths															
	27	1.13	39.7	38.1	38.5		38.8	38.7	38.7	37.4		37.4	37.2		37.1
	48	1.11	39.7	38.3				38.0	37.3	37.4		37.1		37.5	
	47	1.22	38.3	37.2	36.5			36.0		35.9	35.6		35.9		34.7
	39	1.11	39.3	37.7	37.6	37.7	37.1	37.3	37.0	37.5		36.8	37.2		37.4
	23	1.16	39.4	38.1	37.8	37.8	38.3		38.7	37.7		37.3		38.2	
	56	1.12	39.1	38.8		38.3			39.1	38.9		39.1	39.0	38.9	
	16	1.14	38.7	38.1	37.9	38.8	37.7	37.9		37.8		37.7	36.7		38.0
Average			39.2	38.0	37.6	38.2	37.9	37.5	38.1	37.6		37.6	37.2	38.2	36.8
Recoveries															
	29	1.25	38.5		38.5	38.2	38.9		38.6	38.9		38.9		38.4	
	31	1.16	39.0	38.6	38.3	38.3	38.4	38.8	39.0	38.9	39.1		39.2	39.0	
	42	1.15	38.9		38.2	38.0		38.4	38.0		36.6		37.4		38.7
	53	1.15	38.9	38.2	38.1		38.4	38.1	38.2		38.5	38.1		38.3	
Average			38.8	38.4	38.5	38.2	38.6	38.4	38.4	38.9	38.1	38.5	38.3	38.6	38.7

* D = died.

TABLE CXIV (*Continued*)

Temperature Changes of Dogs Gassed with Chlorpicrin

Concentration of Chlorpicrin 153–172 parts per million air (1.11–1.25 mgm. per liter)

Hours after Exposure

12	*13*	*14*	*15*	*16*	*17*	*18*	*19*	*20*	*21*	*22*	*23*	*24-26*	*26-30*	*30-36*	*36-42*	*42-48*	
D																	
D																	
D																	
38.0		38.1		D													
38.0																	
	38.7		38.4		38.1		38.7		36.5				D				
36.5		36.4		36.4			36.8				37.8		D				
	35.6		35.5		35.0			35.7				38.2	37.1	D			
	37.3		37.1		37.2		37.5		37.8			37.0	37.4	D			
38.3		37.8		37.6		37.1			37.8				37.6	D			
38.8		38.5		38.5		38.1		37.8				38.1		39.0	D		
	38.1		37.9		38.0		37.7			38.4				38.7		39.1	D53
37.9	37.4	37.6	37.2	37.5	37.1	37.6	37.6	36.7	37.4		37.8	37.7	37.4	38.8			
38.1		38.7		38.4		39.0					39.3			38.8		39.5	
38.9		38.9		38.7						38.6				39.2			
	39.0		39.0		39.6			39.6				39.7		39.0	40.2	39.3	
38.3		38.6		38.6		38.4		38.9		38.0			37.9	38.7	39.0		
38.4	39.0	38.8	39.0	38.6	39.6	38.7		39.3		38.3	39.3	39.7	37.9	38.9	39.6	39.4	

TABLE CXV

TEMPERATURE CHANGES OF DOGS GASSED WITH CHLORINE

Concentration 800–900 parts per million (2.53–2.85 mgm. per liter)

				Hours after Exposure								
	Dog No.	*Conc.*	*Normal*	*1*	*1–2*	*2–3*	*3–4*	*4–5*	*5–6*	*6–7*	*7–8*	*8–9*
Deaths												
	535	863	39.3	37.7		D*						
	531	893	38.2			33.3	34.8	35.6	35.6		D	
	534	967	38.8		36.8	36.8	35.7	35.3				34.8
	533	845	39.8		38.8	39.0	39.8	39.4	39.7		39.0	
	532	846	38.8	37.7		36.2		36.5	35.4	37.2	37.4	38.2
	528	857	38.6	36.0	34.6		34.0	33.9	33.3	33.4	33.4	33.1
	530	804	38.7	36.0	35.6	35.4	35.0	34.8	35.5	35.8		35.3
Average			38.8	36.8	36.4	36.1	35.8	35.9	35.9	35.4	36.6	37.1
Recoveries												
	529	796	38.5		38.5	35.8	35.6	35.7	35.6	36.0	36.2	36.5

---

* D = died.

TABLE CXV (*Continued*)

Temperature Changes of Dogs Gassed with Chlorine

Concentration 800–900 parts per million (2.53–2.85 mgm. per liter)

Hours after Exposure

9–10	*10–11*	*11–12*	*12–13*	*13–14*	*15–16*	*17–18*	*18–19*	*19–20*	*22–23*	*23–24*	*26–30*
						32.4	D				
39.0		39.0								D	
	38.0		39.7		40.2					D	
32.9	32.7							35.5	33.6	D	
	35.3		35.0	33.9					D		
35.9	35.3										
36.5							37.7		38.5		39.5

APPENDIX

CHAPTER V

METHODS FOR THE COLLECTION AND ANALYSIS OF THE URINE

1. *Analytical Methods*

THE VOLUME and specific gravity of the twenty-four hour samples of urine obtained by catheterization were determined, after which the volume was made up to half a liter with distilled water. The following determinations were made: hydrogen ion concentration by Henderson and Palmer's modification of Sorenson's method; titratable acidity and alkalinity by Folin's method; ammonia by Folin's aeration method; total nitrogen by the Kjeldahl method; creatinine and creatine by Myer's method, using standards of pure creatinine for color comparison; uric acid by Benedict and Hitchcock's modification of Folin's method; phosphates by the uranium acetate titration method; and chlorides by the Volhard-Arnold procedure. From the above data were calculated the percentage of total nitrogen in the form of ammonia, the ratio of phosphates to total nitrogen and the so-called "organic acid" according to Palmer's figures. In addition, qualitative tests were made to detect the presence of protein, sugar, acetone, bile and blood.

2. *Specific Data for Chlorine Poisoning*

a. Concentrations above 2 mgm. of chlorine per liter of air for half an hour. Three dogs (Nos. 3, 60, and 104, Tables CXVI, CXVII, CXVIII) were gassed at concentrations between 2.1 and 2.6 mgm. of chlorine per liter of air. One dog (No. 60) died on the second day, another (No. 104) on the sixth day after gassing, while the third (No. 3) recovered. Protein was found in the urine of the dogs that died. The effects of severe chlorine poisoning as shown by these experiments are most marked on the second day and continue over the third day. They may be summarized as follows:

> Protein metabolism is profoundly affected, as indicated by increased excretion of total nitrogen, creatine and uric acid.
>
> The hydrogen ion concentration, titratable acidity, organic acid figure, ammonia and phosphates are high.
>
> Chlorides are retained during the first 24 hours and greatly augmented elimination takes place on the second and third day.

b. Concentration around 1.6 mgm. of chlorine per liter of air for *one hour*. The data were obtained from three dogs (Nos. 19, 125, and 137 — see Tables CXIX, CXX, CXXI), two of which died on the second day after gassing, while the third (No. 125) succumbed eventually on the eighth day. The urine analysis made on the latter dog during a period of seven days after gassing showed an extreme pathological condition. The pictures presented resemble in all essential respects those of dogs gassed at high concentrations for *half an hour* (compare urine charts for Nos. 104 and 125). Protein occurred in every case. The elimination of chlorides on the first day is low, showing that here also a retention of chlorides occurs during the first 24 hours. (The data at hand indicate that concentrations between 400 and 500 for one hour are lethal.)

c. Concentrations between 0.3 and 0.6 mgm. of chlorine per liter of air. Three dogs (Nos. 36, 93, and 113 — see Tables CXXII, CXXIII, CXXIV) were gassed at average concentrations of 0.40, 0.41 and 0.55 mgm. per liter for *half an hour* respectively. The urine analyses present a picture distinctly different from that already described. The effects of this moderate treatment are:

(a) increased ammonia on the first day.
(b) increased phosphates.
(c) increased chlorides on the first day.

The total nitrogen was not increased in two (Nos. 93 and 113) out of the three cases. The magnitude of the increments of ammonia and phosphates is small in comparison with the effects of higher concentrations. The output of chlorides, however, was greater during the first gassing of one dog (No. 113) at an average concentration of 0.55 mgm. per liter for half an hour than during its second gassing at 1.42 mgm. per liter for one hour. The effects of these low gassings are maximal during the first day, continue to some extent over the second, and disappear on the third. In general there seems to be no profound disturbance of protein metabolism.

d. Concentrations between 0.16 and 0.30 mgm. of chlorine per liter of air for half an hour. The urine of two dogs (Nos. 219 and 277 — see Tables CXXV and CXXVI) was examined during a preliminary normal period covering three days. The dogs were then gassed at concentrations between 0.16 and 0.30 mgm. of chlorine per liter of air for half an hour, and the urine examined during the three following days. No significant change was observed in any of the urine constituents. In addition, four dogs (Nos. 1, 220, 284, and 285, of which No. 1 had been previously gassed) were treated in a similar manner, the urine being analyzed for chlorides alone. In but one of the six dogs gassed at these concentrations was an increase observed in the chloride elimination. In that one case the chloride output was very high on the first day but returned to normal on the second.

TABLE CXVI

The Influence of Chlorine Poisoning upon the Composition of the Urine

Dog No. 3

Urine

Date	*Body Weight*	*Volume*	*Specific gravity*	*P_H*	*Titratable acidity*	*"Organic acid"*	*Total nitrogen*	*NH_3 nitrogen*	*Creatinine nitrogen*	*Creatine nitrogen*	*Uric acid nitrogen*	*Phosphates*	*Chlorides*	*Remarks*
1917	*kilos*	*cc.*			*cc.*	*cc.*	*gm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	
Normal. Before gassing														
July 30	8.0	38	1.051	7.0	16		.93	29	85	17	2	121	50	
" 31		63	1.026	6.0	33		1.71	81	95	46	5	103	31	
Aug. 1		62	1.030	6.2	39		1.69	90	90	62	11	144	14	
" 2		56	1.030	6.2	39		1.63	71	88	55	6	144	6	
" 3	7.7													
After first gassing (2.16 mgm. per liter for 25 min. Aug. 13).														
Aug. 13		84	1.049	6.0	102		3.91	222	90	79	25	485	56	
" 14		80	1.042	6.4	37		3.45	197	88	98	17	120	238	
" 15		71	1.035	6.1	42		2.38	150	86	55	16	145	259	Bile
" 16		44	1.040	6.1	46		1.62	88	86	13	12	159	18	
" 17		43		5.7	36		1.57					125	15	
" 21	8.2													
After second gassing (3.01 mgm. per liter for 30 min. Sept. 3)														
Sept. 3		76	1.064	5.6	123		2.42	139	66	98	24	423	42	Protein
" 4	Died 12.30 P.M.													

TABLE CXVII

The Influence of Chlorine Poisoning upon the Composition of the Urine

Dog No. 60

Urine

Date	*Body Weight*	*Volume*	*Specific gravity*	*P_H*	*Titratable acidity*	*"Organic acid"*	*Total nitrogen*	*NH_3 nitrogen*	*Creatinine nitrogen*	*Creatine nitrogen*	*Uric acid nitrogen*	*Phosphates*	*Chlorides*	*Remarks*
1917	*kilos*	*cc.*			*cc.*	*cc.*	*gm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	
Normal. Before gassing														
Oct. 2		618	1.014	6.7	68		3.67	112	187	76	15	462	931	Protein
" 3		388	1.020	6.3	118		4.19	191	178	59	20	518	014	"
" 4	14.2	325	1.019	5.9	146		4.65	237	177	58	23	537	413	"
" 5		466	1.015	5.7	143		4.48	192	184	52	18	473	194	"
" 6		187	1.030	6.2	83		4.21	184	148	11	14	341	184	"
After first gassing (2.34 mgm. per liter for ½ hr. Oct. 15)														
Oct. 16		189	1.047	6.2	123		8.25	269	135	138	34	608	117	Protein
" 17	Died													

TABLE CXVIII

The Influence of Chlorine Poisoning upon the Composition of the Urine

Dog No. 104

Urine

Date	Body Weight	Volume	Specific gravity	P_H	Titratable acidity	"Organic acid"	Total nitrogen	NH_3 nitrogen	Creatinine nitrogen	Creatine nitrogen	Uric acid nitrogen	Phosphates	Chlorides	Remarks
1917	*kilos*	*cc.*			*cc.*	*cc.*	*gm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	
Normal. Before gassing														
Oct. 30		83	1.042	6.3	69	31	3.09	97	111	17	11	295	70	
" 31		82	1.040	6.3	61	36	2.78	116	116	8	13	254	296	
Nov. 1		86	1.035	6.2	53	34	2.26	116	113	21	8	204	172	
" 2				6.0										
" 3	11.8	69	1.038	6.4	46	10	2.12	79	115	17	8	220	150	
After first gassing (2.58 mgm. per liter for ½ hr. Nov. 12)														
Nov. 12	12.8													
" 13		134	1.042	6.7	32	27	3.66	56	105	54	28	348	234	
" 14		218	1.033	7.0	4	60	5.05	132	122	235	30	532	572	
" 15		170	1.031	6.4	63	33	4.70	323	119	213	28	288	430	
" 16		186	1.032	5.9	57	13	4.18	292	111	147	29	253	176	Blood, protein
" 17		114	1.028	5.9	70	43	4.20	199	107	123	35	301	192	Protein
" 17	Died P.M.													

TABLE CXIX

The Influence of Chlorine Poisoning upon the Composition of the Urine

Dog No. 19

Urine

Date	Body Weight	Volume	Specific gravity	P_H	Titratable acidity	"Organic acid"	Total nitrogen	NH_3 nitrogen	Creatinine nitrogen	Creatine nitrogen	Uric acid nitrogen	Phosphates	Chlorides	Remarks
1917	*kilos*	*cc.*			*cc.*	*cc.*	*gm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	
Normal. Before gassing														
Sept. 4		123	1.041	6.4	104		5.59	198	169	11	17	551	525	
" 5		99	1.042	6.2	77		3.70	183	172	28	15	346	406	
" 6		88	1.046	6.2	66		3.48	136	166	46	14½	296	393	
" 7		76	1.050	6.3	69		3.12	116	165	23	14½	286	300	
" 8		85	1.042	5.9	85		3.40	166	162	18	14½	301	225	
" 10	14.0													
After first gassing (1.41 mgm. per liter for 1 hr. Sept. 17)														
Sept. 17	14.6													
" 18		162	1.046	6.2	128		5.43	177	161	215	23	536	94	Protein
" 19	Died													

TABLE CXX

The Influence of Chlorine Poisoning upon the Composition of the Urine

Dog No. 125

Urine

Date	*Body Weight*	*Volume*	*Specific gravity*	P_H	*Titratable acidity*	*"Organic acid"*	*Total nitrogen*	*NH_3 nitrogen*	*Creatinine nitrogen*	*Creatine nitrogen*	*Uric acid nitrogen*	*Phosphates*	*Chlorides*	*Remarks*
1917	*kilos*	*cc.*			*cc.*	*cc.*	*gm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	
Nov. 12	18.6	*Normal. Before gassing*												
" 13		108	1.040	6.0	75	12	4.09	137	159	22	27	362	69	
" 14		132	1.030	5.9	46	20	4.19	186	160	17	25	260	68	
" 15		92	1.038	5.9	58	12	3.57	153	158	17	22	259	62	Blood
" 16		120	1.032	5.7	61	21	3.93	222	156	19	25	286	54	"
" 17		128	1.031	6.5	45	9	3.55	141	144	28	25	293	103	
		After first gassing (1.54 mgm. per liter for 1 hr. Nov. 26)												
Nov. 27		212	1.030	5.7	131	18	4.97	245	154	108	31	578	73	Protein, blood
" 28		487	1.018	6.0	95	47	6.60	442	167	267	51	532	716	Protein, blood
" 29		458	1.016	6.7	44	84	6.03	331	143	291	44	340	642	Protein
" 30		584	1.012	6.4	43	78	5.68	328	131	179	48	175	600	"
Dec. 1		450	1.015	5.9	70	63	5.69	315	124	92	32	241	332	"
" 2		350	1.020	5.7	78	47	5.45	337	128	79	34	239	103	"
" 3	14.6	499	1.015	5.4	118	44	6.53	416	120	124	49	348	136	"
" 5	Died A.M.													

TABLE CXXI

The Influence of Chlorine Poisoning upon the Composition of the Urine

Dog No. 137

Urine

Date	*Body Weight*	*Volume*	*Specific gravity*	P_H	*Titratable acidity*	*"Organic acid"*	*Total nitrogen*	*NH_3 nitrogen*	*Creatinine nitrogen*	*Creatine nitrogen*	*Uric acid nitrogen*	*Phosphates*	*Chlorides*	*Remarks*
1917	*kilos*	*cc.*			*cc.*	*cc.*	*gm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	
Nov. 19	13.2	*Normal. Before gassing*												
" 20		98	1.040	5.6	90	32	3.49	248	124	39	19	289	220	
" 21		124	1.034	5.5	101	30	3.22	243	128	76	19	328	235	
" 22		108	1.036	5.4	92	24	3.16	210	140	81	29	334	425	
" 23		85	1.042	5.5	73	19	2.71	149	136	68	25	276	456	
" 24		76	1.044	5.5	72	9	2.60	109	128	32	20	282	336	
Dec. 3	12.4	*After first gassing (1.61 mgm. per liter for 1 hr. Dec. 3)*												
" 4		160	1.045	6.6	102	53	5.39	175	104	147	37	649	406	Protein
" 5	A.M.	Found dead												

TABLE CXXII

The Influence of Chlorine Poisoning upon the Composition of the Urine

Dog No. 36

Urine

Date	Body Weight	Volume	Specific gravity	P_H	Titratable acidity	"Organic acid"	Total nitrogen	NH_3 nitrogen	Creatinine nitrogen	Creatine nitrogen	Uric acid nitrogen	Phosphates	Chlorides	Remarks
1917	*kilos*	*cc.*			*cc.*	*cc.*	*gm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	
Normal														
Sept. 27	11.4	88	1.046	6.1	87		3.23	176	116	46	16	297	413	Blood
" 28		87	1.052	6.3	78		3.12	173	153	101	21	348	238	
" 29		82	1.050	6.3	76		2.85	116	112	74	15	300	803	
" 30		88	1.041	6.2	86		2.51	157	121	56	17	336	759	
Oct. 1				6.1										
Oct. 10	11.0	*Normal*												
" 11		103	1,038	7.2	23	16	2.30	77	113	79	14	275	466	Protein
" 12		194	1.024	7.1	58		2.22	167	112	69	16	355	975	
" 13		75	1.040	6.7	77	9	2.46	143	112	70	18	378	138	
" 14		78	1.048	7.0	77	2	2.96	173	103	41	16	357	328	Protein
" 15		93	1.049	7.3	33		3.51	108	100	56	17	365	280	"

TABLE CXXII

The Influence of Chlorine Poisoning upon the Composition of the Urine

Dog No. 36 (Continued)

Urine

Date	Body Weight	Volume	Specific gravity	P_H	Titratable acidity	"Organic acid"	Total nitrogen	NH_3 nitrogen	Creatinine nitrogen	Creatine nitrogen	Uric acid nitrogen	Phosphates	Chlorides	Remarks
1917	*kilos*	*cc.*			*cc.*	*cc.*	*gm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	
After first gassing (0.40 mgm. per liter for ½ hr. Oct. 29														
Oct. 30	10.0	106	1.045	6.4	70		4.10	267	111	57	21	460	258	
" 31		76	1.047	6.0	77		3.35	121	111	35	20	293	71	
Nov. 1		85	1.048	6.1	83		3.37	122	110	24	23	335	121	
" 2		80	1.047	6.1	100		3.31	155	97	26	20	377	40	
" 3	9.0	75	1.048	6.0	76		3.28	214	93	25	21	346	79	
Dec. 3	11.2	*After second gassing (2.79 mgm. per liter for ½ hr. Dec. 3)*												
" 4		267	1.041	7.3	9	211	6.55	191	125	207	37	615	1484	Bile
" 5		300	1.028	6.6	82	49	6.42	407	123	241	34	504	997	Protein
" 6		123	1.038	5.8	70	26	5.10	378	106	132	27	235	550	"
" 7		110	1.033	5.8	81	4	3.71	304	100	36	28	331	17	"
" 8	9.6	101	1.033	5.8	75	16	3.57	316	98	4	19	279	12	"

TABLE CXXIII

The Influence of Chlorine Poisoning upon the Composition of the Urine

Dog No. 93

Urine

Date	*Body Weight*	*Volume*	*Specific gravity*	*P_H*	*Titratable acidity*	*"Organic acid"*	*Total nitrogen*	*NH_3 nitrogen*	*Creatinine nitrogen*	*Creatine nitrogen*	*Uric acid nitrogen*	*Phosphates*	*Chlorides*	*Remarks*
1917	*kilos*	*cc.*			*cc.*	*cc.*	*gm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	
					Normal.		*Before gassing*							
Oct. 22	16.2													
" 23		144	1.033	6.1	121		4.59	332	181	35	28	374	132	
" 24		164	1.027	5.7A* 6.2M	102		4.14	246	186	44	29	331	57	
" 25		168	1.023	5.4A* 6.0M	80		3.44	204	181	11	23	257	88	
" 26		176	1.020	6.2	57		3.31	175	179	2	27	242	63	
" 27		189	1.020	6.1	89		3.73	190	162	13	23	301	70	
				After first gassing (0.41 mgm. per liter for ½ hr. Nov. 5)										
Nov. 5	15.2													
" 6		522	1.014	6.2	109		3.04	385	193	159	51	490	634	
" 7		Ca 500		6.0										
" 8		327	1.016	6.0	76		3.48	252	196	109	35	314	113	
" 9		242	1.020	5.8	105		3.85	297	196	90	35	362	34	
" 10		229	1.022	8.2	—271			1132	172	40	27	442	33	Protein, Cystitis

A* = determined with alizarin.
M = determined with methyl red.

TABLE CXXIV

The Influence of Chlorine Poisoning upon the Composition of the Urine

Dog No. 113

Urine

Date	*Body Weight*	*Volume*	*Specific gravity*	P_H	*Titratable acidity*	*"Organic acid"*	*Total nitrogen*	NH_3 *nitrogen*	*Creatinine nitrogen*	*Creatine nitrogen*	*Uric acid nitrogen*	*Phosphates*	*Chlorides*	*Remarks*
1917	*kilos*	*cc.*			*cc.*	*cc.*	*gm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	
Nov. 5	15.6				*Normal. Before gassing*									
“ 6		94	1.048	6.1	67	30	4.28	188	165	12	28	280	88	
“ 7		84	1.044	6.0	71	25	3.93	192	165	14	28	308	22	
“ 8		95	1.040	6.0	73	19	3.92	203	162	1	25	294	25	
“ 9		96	1.041	6.0	56	24	3.96	190	166	0	23	260	76	
“ 10		90	1.044	5.8	78	20	3.86	208	168	9	25	305	21	
Nov. 19	15.0		*After first gassing (0.55 mgm. per liter for ½ hr. Nov. 19)*											
“ 20		81	1.050	5.9	56	32	4.28	253	166	6	26	365	719	
“ 21		65	1.044	5.8	55	16	3.68	203	160	11	20	273	292	
“ 22		91	1.040	5.5	74	10	3.33	216	155	7	20	291	51	Protein
“ 23		80	1.042	5.4	65	13	3.37	189	158	8	20	235	25	
“ 24		72	1.042	5.4	63	7	3.34	175	150	2	17	255	36	

TABLE CXXIV

The Influence of Chlorine Poisoning upon the Composition of the Urine

Dog No. 113 (Continued)

Urine

Date	*Body Weight*	*Volume*	*Specific gravity*	P_H	*Titratable acidity*	*"Organic acid"*	*Total nitrogen*	NH_3 *nitrogen*	*Creatinine nitrogen*	*Creatine nitrogen*	*Uric acid nitrogen*	*Phosphates*	*Chlorides*	*Remarks*
1917	*kilos*	*cc.*			*cc.*	*cc.*	*gm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	
Dec. 10	14.0		*After second gassing (1.42 mgm. per liter for 1 hr. Dec. 10)*											
“ 11		147	1.044	6.2	95	47	4.46	105	137	59	25	412	28	Protein
“ 12		400	1.024	6.6	52	39	9.55	282	179	368	37	498	373	“
“ 13		372	1.026	6.2	118	60	8.69	445	160	212	32	531	320	“
“ 14		305	1.030	6.6	45	53	7.48	351	141	125	32	278	259	“
“ 15	12.2	275	1.033	6.5	58	51	7.68	261	146	132	33	364	5	“
“ 15	Died P.M.													

TABLE CXXV

The Influence of Chlorine Poisoning upon the Composition of the Urine

Dog No. 219

Urine

Date	*Body Weight*	*Volume*	*Specific gravity*	P_H	*Titratable acidity*	*"Organic acid"*	*Total nitrogen*	NH_3 *nitrogen*	*Creatinine nitrogen*	*Creatine nitrogen*	*Uric acid nitrogen*	*Phosphates*	*Chlorides*	*Remarks*
1917	*kilos*	*cc.*			*cc.*	*cc.*	*gm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	
					Normal.		*Before gassing*							
Dec. 18		154	1.041	5.5	169	33	6.61	275	152	42		553	40	
" 19		132	1.045	5.2	176	37	6.25	326	134	52		555	34	
" 20		130	1.046	5.2	148	22	5.87	328	136	32		506	1	Protein
				After first gassing (0.22 mgm. per liter for ½ hr. Dec. 26)										
Dec. 27		89	1.052	5.0	149	40	5.03	255	133	12		422	43	
" 28		101	1.046	5.7	86	24	5.20	284	132	39		300	20	
" 29		132	1.040	8.0								321	49	Cystitis

TABLE CXXVI

The Influence of Chlorine Poisoning upon the Composition of the Urine

Dog No. 277

Urine

Date	*Body Weight*	*Volume*	*Specific gravity*	P_H	*Titratable acidity*	*"Organic acid"*	*Total nitrogen*	NH_3 *nitrogen*	*Creatinine nitrogen*	*Creatine nitrogen*	*Uric acid nitrogen*	*Phosphates*	*Chlorides*	*Remarks*
1918	*kilos*	*cc.*			*cc.*	*cc.*	*gm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	
					Normal.		*Before gassing*							
Jan. 3		126	1.040	5.8	87	28	5.00	195	133	0		322	21	
" 4		132	1.036	5.7	77	17		190	132	49		303	26	
" 5		172	1.025	5.7	77	17		241	133	51		292	12	Protein
				After first gassing (0.18 mgm. per liter for ½ hr. Jan. 10)										
Jan. 11		52	1.048	5.9	55	7		120	136	10		274	31	Protein
" 12		62	1.044	5.6	49	9		137	135	0		182	17	Protein, blood
" 13		64	1.044	5.6	57	7		118	134	11		229	21	Protein, blood

Data Relative to the Absorption of Chlorine by the Blood

See Footnote, p. 26, Chapter 5

TABLE CXXVII

COMPARISON OF CHLORIDE CONTENT OF PLASMA AND WHOLE BLOOD BEFORE AND AFTER GASSING

Dog No.	*Date* 1917	*Plasma*		*Whole Blood*	
		Inorganic *mgm. per cc.*	*Total* *mgm.*	*Inorganic* *mgm.*	*Total* *mgm.*
2 (Normal)	July 23	6.50		5.51	
	" 24	6.45		5.57	
	" 25	6.50		5.48	5.45
	" 26	6.46	6.48	5.57	5.52
		Average 6.48	6.48	5.53	5.48
2 (Gassed, Aug. 6th, 1.45 mgm. per liter; ½ hour)	Aug. 6	6.65	6.73	5.90	5.90
	" 7	6.70	6.65	5.60	5.66
	" 8	6.70	6.65	5.60	5.60
	" 9	6.45	6.47	5.64	5.64
5 (Normal)	July 30	6.46	6.53	5.38	5.32
	Aug. 1	6.27	6.27	5.32	5.27
	" 2	6.50	6.50	5.45	5.46
	" 3	6.45	6.34	5.45	5.40
		Average 6.42	6.41	5.40	5.38
5 (Gassed, Aug. 13th, 1.95 mgm. per liter; ½ hour)	Aug. 13	6.80	6.75	5.95	5.88
	" 14	6.38	6.45	5.46	5.36
	" 15	6.53		5.45	
	" 16	6.46		5.30	
22 (Normal)	Sept. 6 8:30 A.M.	6.60			
(Gassed, 3.35 mgm. per liter; ½ hour = 10:20 – 11:07 A.M.)	Sept. 6 11:30 A.M.	6.75	6.70		
23 (Normal)	Sept. 6 8:30 A.M.	6.75			
(Gassed, 3.29 mgm. per liter; ½ hour = 9:37 – 10:07 A.M.)	Sept. 6 11:30 A.M.	7.04	6.94		
26 (Normal)	Sept. 10 8:30 A.M.	6.32			
(Gassed, 2.93 mgm. per liter; ½ hour = 10:30 – 11:00 A.M.)	Sept. 10 11:30 A.M.	6.82	6.78		
29 (Normal)	Sept. 11 8:30 A.M.	6.45			
(Gassed, 2.86 mgm. per liter; ½ hour = 9:15 – 9:45 A.M.)	Sept. 11 11:30 A.M.	6.56	6.50		

TABLE CXXVIII

Qualitative Search for Chlorine in the Blood and Plasma of Gassed Animals

(See p. 26, Chap. 5)

KI and Starch Paste Reaction in Protein Free Blood Filtrate

Dog No.	*Date 1917*	*Blood*	*Plasma*	*Dog No.*	*Date 1917*	*Blood*	*Plasma*
14	Aug. 28— 8:00 A.M. Normal	−		17	Aug. 31— 8:00 A.M. Normal	±	
	11:15 " After gassing	+			10:15 " After gassing	+	
	1:30 P.M. "	+			1:00 P.M. "	−	
	2:45 " "	+			3:00 " "	−	
	4:00 " "	+			5:30 " "	±	
	Aug. 29— 8:00 A.M. "	±					
18	Sept. 3— 8:00 A.M. Normal	−	+	12	Sept. 4— 8:00 A.M. Normal		−
	10:30 " After gassing	±	+		11:00 " After gassing		±
	12:45 P.M. "	−	±		3:00 P.M. "		±
	3:00 " "	−	−				
5	Sept. 4— 8:00 A.M. Normal		+	20	Sept. 5— 8:00 A.M. Normal		±
	11:00 " After gassing		++		11:00 " After gassing		−
	3:00 P.M. "		±				
23	Sept. 6— 8:30 A.M. Normal		±	26	Sept. 7— 8:00 A.M. Normal		−
	11:30 " After gassing		±		11:30 " After gassing		−
	1:30 P.M. "		−		1:30 P.M. "		−

Note. — In no case was any immediate development of color observed. The samples were allowed to stand 5–15 hours before taking readings. Under these conditions blanks on the reagents alone very often gave faint positive tests.

PHOSGENE

TABLE CXXIX

INFLUENCE OF PHOSGENE GASSING UPON URINE COMPOSITION

Dog No. 102. Wt. Feb. 27, 18.0 kg.

Date	*Volume*	*Specific gravity*	*P_H*	*Titratable acidity*	*"Organic acid"*	*NH_3 N*	*Total N*	*Creatinine N*	*Creatine N*	*Uric acid N*	*P*	*NaCl*	*Protein*	*Blood*
1918	*cc.*			*cc.*	*cc.*	*mgn.*	*gm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*		
						Normal								
Feb. 28	275	22	6.4	82	38	232	4.03	142	87	21	481	35	+	
Mar. 1	185	28	5.9	78	40	211	3.72	124	134	22	320	22	+	
" 2	145	25	5.8	86	37	228	3.18	122	78	21	340	16	+	
" 3	115	34	5.8	72	34	202	3.05	113	61	19	278	65	+	
" 4	145	31	5.9	61	25	209	3.12	120	68	20	272	50	+	
			Gassed. Average Conc. 60 (0.26 mgm. per liter)											
Mar. 12	170	32	6.4	117	26	188	2.37	83	87	25	564	640	+	
" 13	270	17	6.4	32	19	243	4.06	93	249	34	234	71	–	
" 14	610	12	6.3	41	30	250	3.91	97	141	18	258	1,180	–	
" 15	240	17	6.3	36	25	143	2.15	95	52	26	158	967	Trace	
" 16	195	17	6.1	42	28	141	1.95	97	7	18	180	205	+	Blood

TABLE CXXX

INFLUENCE OF PHOSGENE GASSING UPON URINE COMPOSITION

Dog No. 103. Wt. Feb. 27, 10.2 kg.

Date	*Volume*	*Specific gravity*	*P_H*	*Titratable acidity*	*"Organic acid"*	*NH_3 N*	*Total N*	*Creatinine N*	*Creatine N*	*Uric acid N*	*P*	*NaCl*	*Protein*	*Blood*
1918	*cc.*			*cc.*	*cc.*	*mgm.*	*gm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*		
						Normal								
Feb. 28	65	40	6.2	42	7	106	2.10	91	3	11	257	14	–	
Mar. 1	55	40	6.2	34	16	85	1.62	91	10	9	180	70	–	
" 2	70	37	5.9	40	11	101	1.94	82	18	8	193	74	–	
" 3	55	40	5.9	47	20	95	1.74	86	5	9	212	88	–	
" 4	75	38	5.9	35	2	87	1.85	84	8	8	194	97	–	
			Gassed. Average Conc. 71 (0.31 mgm. per liter)											
Mar. 12	220	18	5.9	81	41	166	2.01	81	7	13	360	1 gm.	+	
" 13	265	16	5.7	63	24	221	3.04	95	131	22	237	443	Trace	
" 14	265	12	5.7	34	11	94	2.07	80	150	14	134	510	"	
" 15	230	12	5.7	45	24	102	1.46	84	11	10	163	314	"	
" 16	185	14	5.5	53	20	95	1.28	81	4	10	174	171	"	

TABLE CXXXI

Influence of Phosgene Gassing upon Urine Composition

Dog No. 115

Date	*Volume*	*Specific gravity*	P_H	*Titratable acidity*	*"Organic acid"*	*NH_3 N*	*Total N*	*Creatinine N*	*Creatine N*	*Uric acid N*	*P*	*NaCl*	*Protein*	*Blood*
1918	*cc.*			*cc.*	*cc.*	*mgm.*	*gm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*		
Normal														
Mar. 7	105	47	6.4	52	11	109	4.13	123	10	10	313	80	+	Blood
" 8	110	47	7.0	24	24	214	4.38	115	15	10	398	310	+	"
" 9	125	48	7.4	0	52	362	4.35	117	11	10	410	350	?	
" 10			6.8										+	
" 11	115(?)	48	6.8	41	18	367	5.13	124	22	13	478	378	+	Blood
Gassed. Average Conc. 63 (0.27 mgm. per liter)														
Mar. 19	140	46	6.4	107	29	225	4.34	106	7	25	650	920	Trace	Blood
" 20	165	46	6.2	112	33	421	7.00	98	196	34	558	39	+	"
" 21	145	40	6.4	52	28	272	5.44	100	210	23	400	940	+	"
" 22	150(?)	34(?)	6.6	40	33	239	4.16	91	71	12	358	528	+	"
" 23	125	35	7.0	9	36	283	3.63	100	9	10	174	147	+	"

TABLE CXXXII

Influence of Phosgene Gassing upon Urine Composition

Dog No. 125. Wt. 11.8 kg.

Date	*Volume*	*Specific gravity*	P_H	*Titratable acidity*	*"Organic acid"*	*NH_3 N*	*Total N*	*Creatinine N*	*Creatine N*	*Uric acid N*	*P*	*NaCl*	*Protein*	*Blood*
1918	*cc.*			*cc.*	*cc.*	*mgm.*	*gm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*		
Normal														
Mar. 19	120	26	6.0	59	16	132	2.68	95	4	9	269	18	–	
" 20	135	24	5.9	46	15	107	2.40	91	2	9	206	70	–	
" 21	120	24	5.8	65	31	101	2.14	87	5	8	226	32		
" 22	125	24	5.9	53	19	93	2.23	91	4	8	218	19		
" 23	135	26	5.7	58	14	102	2.27	91	3	8	237	18		
Gassed. Average Conc. 49 (0.21 mgm. per liter)														
Apr. 2	110	45	6.8	42	15	151	3.30	100	48	15	406	906	–	
" 3	90	40	6.6	29	17	190	3.46	91	164	18	192	65	–	
" 4	100	30	6.3	35	15	164	2.45	93	89	12	170	166	–	
" 5	95	26	6.3	37	13	95	1.65	91	0	9	180	44	–	

TABLE CXXXIII

Influence of Phosgene Gassing upon Urine Composition

Dog No. 454

Date	*Volume*	*Specific gravity*	P_H	*Titratable acidity*	*"Organic acid"*	NH_3 N	*Total* N	*Creatinine* N	*Creatine* N	*Uric acid* N	*P*	*NaCl*	*Protein*	*Blood*
1918	*cc.*			*cc.*	*cc.*	*mgm.*	*gm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*		
							Normal							
May 28	140	34	5.9	112	40	254	4.55	163	88	21	366	174	–	
" 29	150	35	5.7	121	30	220	4.98	155	123	16	412	56	–	
" 30	125	40	5.8	125	25	237	4.52	146	89	18	462	590	–	
		Gassed.	*Average Conc. 93 (0.40 mgm. per liter). Wt. 17.85 kg*											
June 11	175	42	7.4+	Cystitis			4.17	134	14	18	605	360	Trace	
" 12	140	40	7.4+	"			4.55	126	195	13	276	110		
" 13	155	33	7.4+	"			3.88	133	153	16	180	638	+	
" 14	215	25	7.4+	"			4.16	129	27	23	205	595	+	

Gassed June 10, 9:30 A.M.

TABLE CXXXIV

INFLUENCE OF PHOSGENE GASSING UPON URINE COMPOSITION

Dog No. 212

Date	*Volume*	*Specific gravity*	P_H	*Titratable acidity*	*"Organic acid"*	NH_3 N	*Total N*	*Creatinine N*	*Creatine N*	*Uric acid N*	*P*	*NaCl*	*Protein*	*Blood*
1918	*cc.*			*cc.*	*cc.*	*mgm.*	*gm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*		
							Normal							
Apr. 11	800	12	5.9	96	33	227	3.35	146	10	34	380	228	+	
" 12	760	11	6.0	92	41	190	2.92	143	0	42	350	110	+	Blood
" 13	620	11	5.9	80	37	176	3.20	150	12	39	360	152	+	"

Date	*Hour Catheterized*	*Volume*	P_H	*Total N*	*Creatinine N*	*Creatine N*	*Uric acid N*	*P*	*NaCl*
Apr. 22	12:30 P.M.	70	5.5	.426	21	0	5	11	12
	4:30 "	115	5.7	.450	21	1	5	14	14
	8:30 "	110	5.5	.478	21	1	6	26	19
" 23	8:30 A.M.	290	5.5	1.275	65	5	16	155	58
	Total	585		2.629	128	7	32	206	103
	12:30 P.M.	40	6.2	.403	21	0	12	75	48
	4:30 "	100	5.9	.675	22	1	21	202	203
	10:30 "	75	5.8	.813	21	0	23	186	128
" 24	8:30 A.M.	70	5.5	.920	36	2	34	178	
	Total	285		2.81	100	3	90	641	379
	12:30 P.M.	5	5.3	.039	3.3				
	4:30 P.M.	5		.042	3.5				

Gassed at 10:20 A.M.

TABLE CXXXV

INFLUENCE OF PHOSGENE GASSING UPON URINE COMPOSITION

Dog No. 493

Date	*Volume*	*Specific gravity*	P_H	*Titratable acidity*	*"Organic acid"*	*NH_3 N*	*Total N*	*Creatinine N*	*Creatine N*	*Uric acid N*	*P*	*NaCl*	*Protein*	*Blood*
1918	*cc.*			*cc.*	*cc.*	*mgm.*	*gm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*		
						Normal								
June 4	455	12	6.2	66	48	232	3.01	109	1	214	275	1430	–	–
" 5	235	18	5.9	90	42	221	2.59	100	3	179	297	690	–	–
" 6	190	21	5.9	115	54	235	3.20	111	0	208	360	550	–	–
" 7	240(?)	22	5.7	112	52	272	3.61	112	0	208	334	156		
	Gassed June 17th, 9:00 A.M. Average Conc. 68 (0.29 mgm. per liter)													
June 18	270	22	5.9	140	49	190	4.18	82	4	216	543	336	–	–
	Hour Catheterized	*Volume*	P_H											
" 18	12:00 M.	50	5.7				1.06	13	1	56	49	35		
	4:00 P.M.	50	5.7				.84	14	0	41	66	8		
	8:00 "	50	5.9				.80	14	2	44	45	35		
" 19	8:00 A.M.	180	5.7				3.21	35	1	129	209	17		
	Total	230					5.91	76	4	270	369	95		
	12:00 M.	50					1.25	11	1	50	78	5		
	4:00 P.M.	50					1.33	13	1	50	54			
" 20	8:00 A.M.	210					4.66	52		182	262	37		
	Total	310					7.24	76	2	282	394	42		

TABLE CXXXVI

Influence of Phosgene Gassing upon Urine Composition

Dog No. 615

Date	*Hour Catheterized*	*Volume*	P_H	*Total N*	*Creatinine N*	*Creatine N*	*Uric Acid N*	*P*	*NaCl*
1918				*gm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*
Gassed June 26th, 10:30 A.M. Average Conc. 63 (0.27 mgm. per liter)									
June 27	12:00 M.	20		.89	21	21	8.6	59	12
	4:00 P.M.	23		.93	21	33	8.3	75	7
	8:00 "	20		.53	22	4	5.3	64	68
" 28	8:00 A.M.	90		3.13	62	133	20.0	162	48
	Total	153		5.48	126	191	42.2	360	135
	12:00 M.	80		.94	16	34	7.2	46	87
	4:00 P.M.	110		.84	15	32	6.3	39	110
	8:00 "	90		.67	17	32	5.8	42	212
" 29	8:00 A.M.	150		2.14	51	66	19.0	114	409
	Total	430		4.59	99	164	38.3	241	818

PHOSGENE POISONING

Kidney Efficiency Tests

(Phenolsulphonephthalein test)

Dog No. 235

4/10	1:20 P.M.	200 cc. water by sound	
	1:45 "	Injected 6 mgm. phenolsulphonephthalein intramuscularly in the lumbar region. Catheterized and washed bladder.	
	1:50 "	Indicator appears in the urine.	
	2:50 "	Catheterized	57% excreted in first hour
	3:50 "	"	22% " " second "
4/15	10: A.M.	Dog gassed	Average conc. 65 (0.28 mgm. per liter)
4/16	Test repeated		43% in first hour
			20% in second hour
4/19	Test repeated		57% in first hour
			17% in second hour

Dog No. 264

4/17	Kidney Test	53% in first hour
		24% in second hour
4/19	Dog gassed	Average conc. 63 (0.27 mgm. per liter)
4/20	Kidney Test	45% in first hour
		18% in second hour
4/22	Test repeated	60% in first hour
		11% in second hour

CHLORPICRIN

TABLE CXXXVII

Influence of Chlorpicrin Gassing upon Urine Composition

Dog No. 135

Date	Volume	Specific gravity	P_H	Titratable acidity	"Organic acid"	Total N	NH_3 N	Creatinine N	Creatine N	Uric acid N	P	NaCl
1918	*cc.*			*cc.*	*cc.*	*gm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*
Regassed Oct. 21st. 9:00–9:30 A.M. Conc. 119 (0.86 mgm. per liter) Wt. 5.8 kg.												
Oct. 22	50	59	6.2	50	11	2.35	112	51	72	26	247	160
" 23	35	38	6.4	26	8	1.98	41	45	77	18	142	120
" 24	50	42	6.4	46	8	1.58	36	44	10	15	195	40
" 25	40		5.4(?)	52	7	1.62	83	44	3	13	183	Trace
" 26	40	41									162	
Regassed Nov. 25th. 9:10–9:40 A.M. Conc. 76 (0.55 mgm. per liter)												
Nov. 26	85	38	6.2	59	19	2.56	130	49	77	27	275	520
" 27	60	37	6.2	42	21	1.95	66	44	60	15	174	224
" 28	50	46	6.0			2.00	50	43	21	10	202	300

TABLE CXXXVIII

Influence of Chlorpicrin Gassing upon Urine Composition

Dog No. 97

Date	*Volume*	*Specific gravity*	P_H	*Titratable acidity*	*"Organic acid"*	*Total N*	$\frac{NH_3}{N}$	*Creatinine N*	*Creatine N*	*Uric acid N*	*P*	*NaCl*	*Protein*	*Blood*
1918	*cc.*			*cc.*	*cc.*	*gm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*		
Normal														
Sept. 10	140	40	5.7	120	25	5.70	406	114		20	453	150	+	–
" 11	160	35	5.6	115	33	6.53	404	111	114	22	434	44	+	–
" 12	205	35	5.6	152	24	7.45	386	105	130	27	565	74	+	–
" 13	200	45	5.5	152	58	8.77	377	98	164	32	630	36	+	–
Gassed Sept. 23rd. 10:00–10:30 A.M. Conc. 141 (1.02 mgm. per liter) Wt. 9.7 kg.														
Sept. 24	95	60	5.7	152	25	5.08	305	56	85	27	597	70	Trace	
" 25	135	55	5.9	140	15	6.46	245	47	160	32	648	Trace	Trace	
" 25	Died 10:00 P.M.													

TABLE CXXXIX

Influence of Chlorpicrin Gassing upon Urine Composition

Dog No. 181

Date	*Volume*	*Specific gravity*	P_H	*Titratable acidity*	*"Organic acid"*	*Total N*	$\frac{NH_3}{N}$	*Creatinine N*	*Creatine N*	*Uric acid N*	*P*	*NaCl*	*Protein*	*Blood*
1918	*cc.*			*cc.*	*cc.*	*gm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*		
Normal														
Sept. 24	60	55	6.5	50	18	2.35	105	73	58	10	285	50	–	
" 25	170	50	5.9	72	19	2.87	137	72	37	12	323	60	–	
" 26	75	40	5.8	117	67	2.94	197	66	49	12	301	80	–	
" 27		Fever in sample — Diarrhea												
" 28	120	25	5.8	58	13	2.69	210	60	35	11	247	55	–	
Gassed Oct. 7th. 10:20–10:50 A.M. Conc. 124 (0.90 mgm. per liter) Wt. 6.3 kg.														
Oct. 8	75	45	5.6	90	6	2.78	193	46	39	23	363	Trace	–	
" 9	95	42	5.9	80	10	4.34	213	45	167	38	349	Trace	–	
" 10	75	44	6.4	45	12	2.90	67	32	98	31	266	Trace	–	
" 11	Found dead in morning.													

CHLORPICRIN POISONING

Kidney Efficiency Tests

(Phenolsulphonephthalein test)

Dog No. 353

Test on the normal dog November 20 10 : 00–12 : 00 A.M.
Dye appeared in the urine in 8 minutes.

	Standard	Unknown	
First hour	20	18	=56%
Second hour	20	30.5	=16%
		Total	72%

Dog gassed November 20
Test run November 21 9 : 40–11 : 50 A.M. 24 hours after gassing
Dye first appeared in 8 minutes.

	Standard	Unknown	
First hour	20	15.7	=64%
Second hour	20	27.0	=19%
		Total	83%

Test November 22 9 : 50–12 : 00 A.M. 48 hours after gassing
Dye appeared in urine in 5 minutes.

	Standard	Unknown	
First hour	20	13.8	=72%
Second hour	20	22.0	=11%
		Total	83%

November 23 Dog was found dead.

Dog No. 354

Test on the normal dog November 20 9:50–12:00 A.M.
Dye appeared in the urine in 5 minutes.

	Standard	Unknown	
First hour	20	17.3	=58%
Second hour	20	34.0	=15%
		Total	73%

Dog gassed November 20
November 21 9:20–11:30 A.M. 24 hours after gassing
Dye appeared in the urine in 5 minutes.

	Standard	Unknown	
First hour	20	19.0	=53%
Second hour	20	27.8	=18%
		Total	71%

November 22 9:30–11:40 A.M. 48 hours after gassing
Dye appeared in the urine in 6 minutes.

	Standard	Unknown	
First hour	20	21	=48%
Second hour	20	24	=21%
		Total	69%

November 23 9:20–11:30 A.M. 72 hours after gassing
Dye appeared in the urine in 6 minutes.

	Standard	Unknown	
First hour	20	20.5	=49%
Second hour	20	28.5	=18%
		Total	67%

Dog survived.

The above results indicate that the kidneys were not damaged to any extent due to the primary effects of the gas poisoning.

APPENDIX

CHAPTER VI

Determination of Total Solids of the Blood

The samples for the determination of the total solids in the blood were drawn by needle from the jugular vein. These specimens were carefully dried to constant weight at 105° C.

TABLE

Total Solids of Blood of

II A. Animals dying

Dog No.	*Gas Conc. mgm. per liter*	*Before gassing*	*Hours after Exposure* 1	2	3	4	5	6	7	8	9	10	11	12	13
P724	0.18	22.0				20.7			21.5				24.2		
P729	0.21	20.7	19.6	19.8	19.8	19.9	21.8	24.3		26.0					
P723	0.20	20.0			19.7				22.0				24.4		
P712	0.21	16.8	19.9	19.5	19.1	19.5	19.2		19.2		20.1		21.4		22.4
P698	0.25	18.7	19.4				19.0				22.0				
P684	0.23	22.8			23.0				25.0						
P486	0.30	19.4	18.0			20.0					21.5				21.7
P124	0.29	21.3	18.9		19.1		22.0				24.5			25.7	
P350	0.29	18.6				18.8				19.5				21.0	
P368	0.30	17.1		17.0				18.0				18.8			
P727	0.26	20.8	19.5	19.5	20.3	20.3		23.6							
P426	0.34	20.9													
P386	0.34	19.1		17.3											
P431	0.31	17.4	17.2				17.6				19.4				20.3
P361	0.33	18.2		15.6				16.5							
P395	0.34	21.8		18.8				21.9							
P139	0.38	22.0	19.5		21.5			24.4							
P140	0.38	21.8	20.1		21.1		20.9				23.8			25.7	
P322	0.38	21.4		21.4				23.2				25.2			
P351	0.38	20.7		20.6				23.3							
P257	0.40	22.7	20.5			21.3			24.8			26.2			
P406	0.49	21.8	19.6			20.5			22.7					27.1	

CXLI

Dogs Gassed with Phosgene

during the Acute Period

Hours after Exposure																
14	*15*	*16*	*17*	*18*	*19*	*20*	*21*	*22*	*23*	*24–25*	*26–27*	*28–29*	*30–31*	*32–33*	*42–43*	*45–50*
	25.8				25.8				25.5				24.8			
	23.9															
	24.6		24.3			25.6			25.6			26.4				
	28.6															
		22.6				23.2				22.9		22.8				
				22.3				23.2			22.9					
		23.6						22.8								
					22.3											
									27.2		26.6					
									26.3							
26.0				25.7				24.8								
									24.2		23.4					
									27.5							

TABLE CXLII

Hemoglobin Changes in Phosgene Poisoning

Concentration 60–70 parts per million (0.26–0.30 mgm. per liter)

Acute Deaths

Dog No.	*734*	*735*	*737*	*740*	*749*	*750*	*760*	*739*	
Conc.	*69*	*61*	*69*	*67*	*69*	*62*	*65*	*68*	*Average*
Hours									
0–1					94	104	90		96
1–2	74	76	83	81		115		114	90
2–3					95		92		95
3–4	77	98	98	80	95	105		110	
4–5	83	111					96		100
5–6			105		102	104			
6–7	87	113		83	95	100	99		100
7–8								125	
8–10	102	131	114	80	126	129		124	115
10–12					143	150	156		139
12–14		123	150	117	140	153	155		
14–16	100		148	105	173				131
16–18	132	150					134		133
18–20				111			147		
20–24									
24–28									
28–32									

7	28–29	30–31	32–33	34–35	36–37	38–39	40–41	42–43	44–45	45–50
			22.1							
				21.5						
	23.4							22.6		
	23.3					23.1			21.8	
	18.1					17.6			17.2	
	25.0									
	24.7			23.0						
	21.3									
		20.8			20.3					
		23.6			24.7					
		22.2		20.1						
		21.5			23.0					
									25.0	
		24.7			23.8					
	21.2							20.4		
	24.8							22.8		
						22.6				
		19.8			19.9					
								19.5		18.2
		21.3								19.4
		23.7			21.4	22.4				21.0
		22.0			21.5					
		24.6	25.0				24.6		22.2	22.0
		22.4								20.7
		20.4								19.2
		25.6						20.0		21.8
		25.3			23.7				23.7	23.0

TABLE CXLIII

Hemoglobin Changes in Phosgene Poisoning

Concentration 70–80 parts per million (0.30–0.35 mgm. per liter)

Acute Deaths

Dog No.	*768*	*777*	*779*	*782*	*783*	*690*	*769*	
Conc.	*79*	*80*	*78*	*77*	*76*	*74*	*73*	*Average*
Hours								
0–1	98	103		105	94		98	99
1–2			94			136		104
2–3	93	101	89	110	89	131	95	
3–4							101	105
4–5	95		137	103	88			
5–6	100	99				141	98	109
6–7				108	83	149	93	
7–8	103	102						117
8–9		103		132	104		157	
9–10	119							136
10–12	120	117					188	
12–14								
14–16	146	132			149	122		137
16–18								
18–20	136							138
20–22		139						
22–24	147							
24–28		126						136
28–32								

TABLE CXLIV

Hemoglobin Changes in Phosgene Poisoning

Concentration 40–50 parts per million (0.17–0.21 mgm. per liter)

Recoveries

Dog No.	*663*	*700*	*702*	*703*	*704*	*705*	*708*	*715*	*716*	*717*	*720*	*731*	*732*	*730*	*714*	*713*	*711*	*680*	*679*
Conc.	*50*	*43*	*50*	*45*	*47*	*47*	*45*	*45*	*46*	*46*	*47*	*49*	*49*	*50*	*44*	*43*	*41*	*43*	*45*
Hours																			
0–1		125		90	112	84			99	81			91	100		84			
1–2	111		88	80			81	88			90	78	78	101	85	72	107	101	102
2–3		112	84		101	88	82		102	87	91	87		93	85	73	100	101	98
3–4	102			73			83	100	95	105	92		83	86	93	79	102	97	100
4–5	100		97	79	101	83		102		90		91			93	80	110	97	89
5–6	104	125	80		97	95		103	103	87		106	84	84			106	100	94
6–7	100	120		101		88	106	92	99		97		78	85	92	84	125	104	104
7–8	102	142	84		101							94							
8–9									111	98	108			90	89	86	121	106	115
9–10				121	118		106	115					95						
10–12	103	133	103	107		108	115		117	115		107		94	111	108	114	100	113
12–14	128	132	91		109	111		119			128	95	91	100	111	94	120	106	135
14–16	114	162	104	117	127	112	106	110	124	123	139			97		82	107	104	125
16–18	106		98	113	136	106	134			130		115	116		107	94	113		
18–20		183		111			110	119	122		144 135	112	109	109	108	93		118	121
20–22	111	182	105		118	119		119	130	139	142			91			110	118	109
22–24	109		97	117	120	97	89		122	128	130	99	96		105	95	113	109	117
24–26		162		85	97	78		119	120		131			100					
26–28	104	156	105					108		117									
28–30									123	110					119	101	118	117	133

TABLE CXLV

HEMOGLOBIN CHANGES IN PHOSGENE POISONING

Concentration 51–60 parts per million (0.22–0.26 mgm. per liter)

Recoveries

Dog No.	*664*	*671*	*672*	*692*	*693*	*694*	*696*	*718*	*719*	*722*	*652*	*653*	*654*	*666*	*667*	*668*	*670*	*669*	*683*	*728*
Conc.	*51*	*52*	*58*	*53*	*59*	*56*	*59*	*51*	*51*	*52*	*54*	*54*	*55*	*53*	*56*	*55*	*54*	*53*	*54*	*57*
Hours																				
0–1		87	103	102	109			78			111	93	85			82	84			
1–2	66	84	105			88		91	98	96	98	89	78	80	83	92	83	89		82
2–3	65			100	102				88	96	92		80	83	87	95	83			81
3–4	75	92	102				102	102	81	82	104	89		82	95		83		113	84
4–5		98	97	100	100	90		91			106	90	77	78	95	85	86			83
5–6	68	115	94			98	99	91		100	108			84				91		
6–7	72	90	96	120	109	96	97		91		101	104	81	73	114	89	94		123	83
7–8	73			100	107															
8–9							107	100	102	117	102	116	99	95	129		101	98		86
9–10		116	118		117	109														
10–12	84	121	130	111	129	123	121	106			131	118	98	90	130	107	108		120	105
12–14	94	112	126	111		125	131		103	128	136	130		89	130	117	97	120		116
14–16	83		130	111	117			116	105	141	145	139	100	85	129		111		130	109
16–18	90	125				129	135	116		128	148	139	102	90	142	118	111	127		122
18–20		111	134	112	139				110	128	133	130	114	103	134	120	111		153	121
20–22	92	119	113	125	129	117	138	116	98	135	149	157	103	103	113	128	116	122		
22–24	102	126					133	106	128	144		127	96						131	102
24–26		112	106	111	152	105		101	120	141	129	140	101	117	111	118	123	122		99
26–28	104						94													
28–30		105	128	106	136	110								102	117	115	119	116	137	

TABLE CXLVI

HEMOGLOBIN CHANGES IN PHOSGENE POISONING

Concentration 60–70 parts per million (0.26–0.30 mgm. per liter)

	Recoveries											*Delayed Deaths*			
Dog No.	*733*	*736*	*747*	*752*	*753*	*754*	*755*	*758*	*759*	*767*	*Average*	*751*	*738*	*757*	*766*
Conc.	*68*	*63*	*63*	*63*	*64*	*62*	*65*	*67*	*65*	*65*		*62*	*61*	*66*	*67*
Hours															
0–1	84	83				94		91	91	87	88	87		93	89
1–2			93		90		87				90	87			77
2–3	87		91		87	80		88	98	93		108	94	101	
3–4	90	93	93		98	73	86				87	111	103		88
4–5		87		96	74	73		89	101	87	89			106	86
5–6	78	108	82				93			90	90	98			
6–7	84				90	86		105	133	87	96	103		123	86
7–8			72				101				98		96		85
8–10	93	130	80	87	110	137				101		106		168	95
10–12			78	96		140	117	113	143	115	114	106	93		113
12–14	94		97		112	140					117	107	137		109
14–16		155	89	98	134	165	117	111		114		121		164	
16–18	124			120			117	111	123		119	147	142		104
18–20	124	153	86	117			110	100		114	115		129	150	103
20–24	105	122	84		116	125	108	100	111	101	108	112	146	164	119
24–28		133		106						114					
28–32		119													

28–29	*30–31*	*32–33*	*34–35*	*36–37*	*38–39*	*40–41*	*42–43*	*44–45*	*46–50*
23.1		22.3		22.0		22.3		22.3	
25.1		23.2		22.6		22.0		21.3	20.3
	16.6		17.0	16.4			16.1		15.3
	22.1		21.3		20.9				20.2
		22.7		21.1		22.8			22.6
24.1		25.5		24.2		24.3		23.7	23.0
	21.8		20.9		19.9		19.4		19.5
		22.3		21.1		20.8			20.4
21.2	21.5		20.6		20.4		20.5		
	29.4		22.2		23.8		23.5		23.2
	18.0		16.9		17.5			17.9	17.4
21.0		19.7		20.3		19.1		19.3	19.5
	21.1		19.8		20.8		20.6		20.6
22.9		23.0		22.1		22.7			
	22.9		25.2		24.6			23.5	22.8
22.8				21.8		22.1			
	19.8		19.4		18.8			19.9	19.7
	23.5		22.9		23.0		21.6		24.4
		19.3				19.1		19.4	
20.3		20.2		19.7		19.2			
	24.1		23.7		23.8		23.4		23.0
	23.1		23.3		23.8			22.0	22.2
24.8	23.5		23.3			22.5			
22.4		22.1		21.5		21.4			
	20.4		21.0			20.6			
22.4		22.1		22.2		23.0		22.4	21.6
	22.9			25.0		19.8			
23.3		23.2		23.4					
	21.0		20.7		20.4		20.5		
21.5		21.4		22.3		21.0		20.6	

TABLE CXLVII

HEMOGLOBIN CHANGES IN PHOSGENE POISONING

Concentration 70–80 parts per million (0.30–0.35 mgm. per liter)

	Recoveries								*Delayed Deaths*					
Dog. No.	*763*	*765*	*770*	*776*	*778*	*781*	*784*	*Average*	*761*	*762*	*764*	*785*	*780*	*Average*
Conc.	*73*	*75*	*76*	*79*	*76*	*76*	*72*		*72*	*80*	*73*	*74*	*76*	
Hours														
0–1	81	88	96	103	105			94	96	92	95			94
1–2	74	79				85	81	81	91	90	101	74	86	88
2–3			90	98	90				92	94				93
3–4	88	91	89			80	83	86	100	103	105	76	80	
4–5	81	96		94	94			91			101			93
5–6			88			97	91	92	95	91		80	98	
6–7	76		98	91	94		77	89			111	75		93
7–8						85			89	91	114		80	
8–9			105	86	96		102	94	98	98		64		95
9–10		106			99	90					123		96	
10–12	105	130	116	109				115	100	94	128			112
12–14									125	114				
14–16	98	123	120	121	141	101	112	117			148	108	117	123
16–18									125	113				
18–20	95	136	100			105	122	113	121		147	112	109	122
20–22				100	135					119				
22–24		128	100			104	117	112				105	113	115
24–28	86	120	129	111	125		105	113	101	121	143	104		
28–32	98				116	105		106	125	122	154		117	129
50–55									98					98

TABLE

TOTAL SOLIDS OF BLOOD OF

II. Animals dying during

Dog No.	*Gas Conc. mgm. per liter*	*Before gassing*	*Hours after exposure*												
			1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*
CP253	0.58	19.2	22.5	22.2	24.4	25.6			26.8		26.8		25.9		
CP249	0.73	21.7	23.4	25.9	26.8	27.4		28.6		29.2		29.2		29.1	
CP243	0.74	17.6	18.7	19.7	20.3	20.5	23.0		22.2		21.5				
CP227	0.79	23.8	26.3	27.2		28.6	27.5								
*CP206	0.81	22.7	23.6		23.8	24.8		24.2		24.6		25.3		25.3	
CP294	0.84	21.0	21.1	22.3	21.9	22.6	23.3		22.7		22.6		23.2		
CP204	0.85	21.7	21.6	22.9		24.2	23.5		23.9		24.0		23.3		
*CP205	0.86	18.5	18.9	20.2	21.1	21.4	21.0		21.9		22.5		22.8		22.0
CP220	0.83	17.4	19.1	20.9	22.3	23.0									
CP191	0.91	20.1		23.7	24.6	26.6	27.5		27.1						
CP211	0.92	24.4	25.3	26.7	28.3	28.8	29.0	28.7		29.4		28.5		28.9	
CP186	0.97	19.9	20.5	21.4		22.7	21.9	22.7	22.9		23.5		24.0		22.0
CP177	0.96	23.9		26.5				29.0				29.2			
CP212	0.97	20.8		23.0	23.5	25.6	25.9	26.1		26.3		26.7		26.4	
CP187	1.00	20.7			25.7		27.4	28.3							
CP178	1.01	16.7		16.6				19.7							
CP193	1.15	22.5	23.4	23.9	23.9	24.4	23.5	24.8		25.1				26.6	
CP317	1.14	23.4	25.6	27.7	27.8	29.4		28.8		28.8					
CP316	1.08	21.9		25.1	26.8	27.6	28.1		29.5		29.0				
CP326	1.09	21.0	21.8	24.3	24.5	26.1		27.1		27.4					
CP312	1.14	23.0	23.0	23.1	24.6	25.7	26.0		26.5		26.2				
CP331	1.16	22.7	25.1	26.4	27.5	28.6									
CP332	1.16	18.4	20.3	22.3	23.9										

*Killed in error.

CXLIX

Dogs Gassed with Chlorpicrin

the Acute Period

								Hours after exposure								
14	*15*	*16*	*17*	*18*	*19*	*20*	*21*	*22*	*23*	*24–25*	*26–27*	*28–29*	*30–31*	*34–36*	*37–40*	*41–45*
26.2		25.4		25.1				24.9								
	25.0		25.3		24.2		24.1									
	23.1				23.4			22.2			22.6		22.8	22.9	24.4	
23.6		23.5		24.2		23.5				24.8						
	22.3		21.4				21.5		21.4							
29.2				29.6		29.7										
	23.7		23.6		23.2		23.3			23.2		23.4			22.2	21.4
28.8																
26.1		26.2				25.3										
	24.7		25.1			25.0				24.5		24.4				
28.5		28.2		27.5				27.3								

TABLE CL

Determination of Hemoglobin on "Blood Solid" Dogs Gassed with Chlorpicrin

Concentration 0.51–0.65 mgm. per liter (70–89 parts per million)

	Recoveries							
Dog No.	*252*	*259*	*260*	*266*	*272*	*273*	*274*	*Average*
Hours								
0–1	124	105	112	101	101	89	98	104
1–2	112	110	103	104		105	111	107
2–3	111	93	104	109	106	102	108	105
3–4	114	112	123	104	109	100	113	111
4–5	111	123	117	110	100	114	132	114
5–6					118			
6–7	130		117			114		120
7–8					126		133	130
8–9	110	122	119	111		114		117
9–10					128			
10–11	109	123	120	110		114	133	120
11–12					131		122	
12–14	102	124	117	120	126	100	113	117
14–16	97	125	117	97	117	100	109	111
16–18	101	124	115	95	112	100		109
18–20	102	127	112	90	109	92	111	107
20–22	100	104					108	104
22–24	105	110	105	98	107	97		105
24–26							108	
26–28	106	100	95	89	101	101		100
28–30	111			89			117	
30–34	112	99		88		105	112	105
34–38	102		89		110	85	108	97
38–42	104		80	77	110	89	97	96
42–46	104	94		76	106	89	97	94
46–50	106		89		117	89		99

TABLE CLI

Determination of Hemoglobin on "Blood Solid" Dogs Gassed with Chlorpicrin

Concentration 0.66–0.80 mgm. per liter (91–110 parts per million)

	Recoveries									
Dog No.	*226*	*233*	*234*	*238*	*239*	*244*	*248*	*265*	*267*	*Average*
Hours										
0–1	105	100	120	88	89	96	107	93	96	100
1–2	117	112	133	80	79		116	96	93	103
2–3	111	112	132	77	83	100	125	87	83	101
3–4		117	139	83	103	101	140	96	93	109
4–5	126	119	132	83	102	94	117	96		109
5–6				85				101		
6–7		117	132		93	94	117			106
7–8	126			76					93	
8–9			131		102	92	97			106
9–10	122	117		76				111	93	104
10–11		117	129			92	100	108		108
11–12	122		128	69						108
12–14	126	107	121	67	92	90	106	105	93	101
14–16	126	98	119	67	97	88	103	106	90	99
16–18	121	100	107	67	97	86	105	96	90	97
18–20	120	98		67	97	86	104	96		94
20–22									98	
22–24	119			80	113	90	110	105		99
24–26		96	102						93	99
26–28			102	85	107	88	112	98		99
28–32		98	102	80	98	84	100	98	101	99
32–36		103	90	76	92	83	98	96	98	94
36–40		107	93	72	97	84	85	87	93	92
40–44		90		71	92	86	93	83	92	86
44–48				71	90		101	84	89	87
48–52			102		89					95

TABLE CLII

Determination of Hemoglobin on "Blood Solid" Dogs Gassed with Chlorpicrin

Concentration 0.81–0.95 mgm. per liter (111–131 parts per million)

	Recoveries										
Dog No.	*190*	*204*	*205*	*206*	*219*	*223*	*224*	*294*	*298*	*299*	*Average*
Hours											
0–1	91	98	105	96	95	113	100	92	102	97	99
1–2		97	117	100	105	108	117	101	106	102	106
2–3	103	107	119	101	122	129	115	103	100	105	110
3–4	106	101	127		118	140	130	113	103	106	116
4–5	100	109	135	120	120	120	129	127	109	112	118
5–8	108								118		
6–7		109	127	112	129	120	120	113	113	109	117
7–8	123			112							
8–9		113	136		122	120		109	113	102	117
9–10	111			112						106	
10–11		114	138		134	120	120	106	118		118
11–12	111										
12–14	120	117	136	112	136	133	132	105	111	90	119
14–16	107	113	139	110		131	132	99	100	90	114
16–18	106	114	140	110	135		130	97	95	90	113
18–20	105	113	140	106	134	133	116	97	95		115
20–22				110			113			97	
22–24		122	140			148	126	101	124		120
24–26										100	
26–28					129			96	116		109
28–32								98	89	94	
32–36	114				111			105	103	96	101
36–40	108				105			107	106	96	105
40–44	103							105	100	90	99

TABLE CLIII

Determination of Hemoglobin on "Blood Solid" Dogs Gassed with Chlorpicrin

	Concentration 0.96–1.10 mgm. per liter (132–151 parts per million)						Concentration 1.11–1.25 mgm. per liter (153–172 parts per million)		
	Recoveries						*Recoveries*		
Dog No.	*182*	*183*	*186*	*192*	*293*	*Average*	*311*	*325*	*Average*
Hours									
0–1	93	96	101	102	100	100	97	98	98
1–2	93	109	100	110	100	102	105	102	104
2–3	99	111		111	108	107	130	113	122
3–4	97	110	109	112	110	108		114	
4–5	96	113	103	118	102	107	138	120	129
5–6	88	115	103	120	117	109	138	120	129
6–7		114	107		118	113	138	113	126
7–8	91	116		113	118	109			
8–9			107				125	116	121
9–10	88			120	121	109			
10–11		115	109				122	116	119
11–12	96	108		111	122	110			
12–14	91	104	108	116	114	107	127		
14–16	88	99	114	99	108	102	127	116	122
16–18	91	94	115	94	97	98	125	116	121
18–20			109	94	91		146	116	131
20–22		89	115		98	98	141	121	131
22–24	86	89		98	96	92			
24–28	88			94	90	91	138	121	130
28–32	78	77	112		81	87	114	120	117
32–36	73	69	107	100	82	84	105	110	108
36–40		69	113	93	87	90	111	120	116
40–44	73		117	84	94	92	114	116	115
44–48				75	92	84			
48–52					83	83			
52–56							96		96

TABLE CLIV

Determination of Hemoglobin on "Blood Solid" Dogs Gassed with Chlorpicrin

	Concentration 0.51–0.65 mgm. per liter (70–89 parts per million)	Concentration 0.66–0.80 mgm. per liter (91–110 parts per million)			
	Deaths	*Deaths*			
Dog No.	*253*	*227*	*243*	*249*	*Average*
Hours					
0–1	110	108	112	101	107
1–2	137	114	113	119	115
2–3	142		146	125	136
3–4	142	124	146		136
4–5	142	129	140		138
5–6					
6–7	149			129	129
7–8					
8–9	166		140	134	137
9–10					
10–11	161				
11–12	154		133		133
12–14	152			137	137
14–16	152				
16–18	152				
18–20					
20–22	160				
22–24	145				

TABLE CLV

Determination of Hemoglobin on "Blood Solid" Dogs Gassed with Chlorpicrin

	Concentration 0.81–0.95 mgm. per liter (111–131 parts per million)				Concentration 0.96–1.10 mgm. per liter (132–151 parts per million)		
	Deaths				*Deaths*		
Dog No.	*191*	*211*	*220*	*Average*	*187*	*212*	*Average*
Hours							
0–1	101	106	108	105	111	113	112
1–2	115		132	124		118	118
2–3	115	112	150	126		118	118
3–4	121		149	135	112	136	124
4–5	135	136		136	120	147	134
5–6					122	157	139
6–7	134	136		135			
7–8		136		136		154	154
8–9							
9–10		136		136		156	156
10–11							
11–12		136		136		156	156
12–14		136		136		154	154
14–16						153	153
15–16		154		154			
16–18						140	140
17–18		142		142			
18–20						145	145
19–20		138		138			

TABLE CLVI

Determination of Hemoglobin on "Blood Solid" Dogs Gassed with Chlorpicrin

Concentration 1.11–1.25 mgm. per liter (153–172 parts per million)

	Deaths							
Dog No.	*193*	*312*	*316*	*317*	*326*	*331*	*332*	*Average*
Hours								
0–1	98	127	102	116	101	107	113	111
1–2	99	145	120	130	100	112	137	120
2–3	102		128	132	120	116	154	125
3–4	108	162	129	129		126		131
4–5	106	158	131	126	154			135
5–6	111	150		114				
6–7			122		154			130
7–8		139		110				
8–9					152			134
9–10	105	139		124				123
10–11								
11–12	106			114				110
12–14	107			120				114
14–16	107			118				113
16–18	111			122				117
18–20	111			123				117
20–22				117				
22–24	101							109
24–26	103							103

TABLE

Hemoglobin Determinations

Concentration 0.51–0.65 mgm. per

Dog No.	*Conc.*	*Normal*	*Hours after exposure*													
			−1	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*
Acute Deaths																
277	0.64	100	132	154		167	169	162	179	173	171	173	169	160	158	161
261	0.60	100		113	115	121	139	127	126	132	136	124	119	119	116	133
Average			132	133	115	144	154	144	147	102	153	148	144	139	137	147
Delayed Deaths																
8	0.62	100	114	131	154	147	148	156	160	175	170		165		156	
5	0.62	100	124		122	125	138	128	122	112		127		130		128
Average			119	131	138	136	143	142	141	143	170	127	165	130	156	128
Recoveries																
1	0.64	100	105	93		94	104	106	104	105		105		89		103
4	0.57	100	105	105	105		110	113	113	107	107		98		99	
255	0.58	100	100		99	99	99	100	100	100	99	106	107	107	107	109
256	0.62	100			94	89	84	81		92	93	108	112	114	114	112
257	0.56	100	104	101	99		100	102	102	104	102	99	99	104	91	93
262	0.62	100	97	99	97	95	99	101		101	103	103	113	113	113	113
263	0.58	100	103	103	107		106	107	107	110	115	124	116	121	123	121
268	0.65	100	100	100	104	105	111	107	121	121	114	113	113	116	106	103
270	0.59	100	98	96	100		104	108	115	128	128	117	117	117	107	103
278	0.64	100	104	109	109	112	126	120	112	110	112	112	116	110	109	109
279	0.64	100	112		115	124	124	123	126	129	130	134	140	129	124	124
280	0.61	100	98	94	104	104	107	108	111	113	110	110	106	110	113	106
281	0.65	100	96	96	100	102	102	106	107	109	108	118	112	109	109	
282	0.58	100		94	103		107	111	109	107	101	100	87	83	85	77
285	0.60	100	121	132	136		144	124	124	123	126	125	125	132	129	133
289	0.60	100	124	133	116	127	123	120	123	136	130	134	136	137	136	137
290	0.63	100	106	111	120	122	130	131	130	131	130	135	134	134	134	133
295	0.51	100	109	119	122	125	124	122	117	119	112	109		113	115	117
Average			105	106	108	108	111	111	114	114	113	115	114	114	113	112

*D = died.

CLVII

in Chlorpicrin Poisoning

liter (70–89 parts per million)

Hours after exposure														
14	*15*	*16*	*17*	*18*	*19*	*20*	*21*	*22*	*23*	*24–26*	*26–30*	*30–36*	*36–42*	*42–48*
162D*														
136	136	132	128D											
149	136	132	128											
167		142		149		131		136		142	D			
	119		133		133			138		131		D		
167	119	142	133	149	133	131		137		136				
	111		112		114		114			105	98	91		99
102		96		102		93			84	94	93			
109	109	109			110									
112	112	112			112									
95	95	105	105	105	105	105	100	100		105				
113	113	107			113									
121	123	121	121	120	116	113	106				138	121		117
	103	100					132			125		104		
106	106	103	100	98	97	93	92	90		98				
98	96		90	86		90		123						
124		124		124		124		128						
106		106		103	103		106							
109		106	97		109									
75	74	74	77	77	75	71	61					68		
139	142	141	139	142	142	133		124		141				133
137	136	137	139	134		133		147						108
130	132	122	127											97
117		117	109		104									
112	112	111	110	109	108	106	102	102	84	111	110	96		111

TABLE

HEMOGLOBIN DETERMINATIONS

Concentration 0.66–0.80 parts per

Dog No.	*Conc.*	*Normal*	*Hours after exposure* −1	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*
Acute Deaths																
247	0.69	100		99	105	117	128	132	130	130	117	139	D*			
225	0.73	100		118	112		152	152		139	152	166	D			
188	0.75	100			103	94		106		102	102	102		103		103
Average				109	107	106	140	130	130	124	124	136		103		103
Delayed Deaths																
236	0.67	100		98	96		102	106	110	122	122	122	122	122	122	113
216	0.78	100		130	143	151	158	172	179	184	186	190	186	184	179	174
251	0.70	100	108	113	122		136	137	135		126	125	123	123	122	120
Average			108	113	120	151	132	138	141	153	144	145	143	143	141	135
Recoveries																
2	0.70	100	105	93		94	104	106	104	105		105		89		103
3	0.66	100		101	108	102	105		124		109		109		109	
6	0.75	100		105	109	110	88	86	79		95		95		110	
7	0.80	100	97	83	94	97		94		98		107		101		111
9	0.71	100	110	99	116	114	119	129	129	116		132		130		123
13	0.76	100	92	101	104	113	110	108	106	99		98		97	105	
221	0.77	100	111	109	105	106	106	112	114	117	121	125	125	125	123	122
222	0.78	100	100	100	114	114	112	114	123	133	134	134	133	131	129	131
228	0.75	100	127	122	138	135		137	140	145	145	149	151		155	160
231	0.68	100	98	105	103		109	112	108	105	105	114		118	122	122
232	0.80	100	99	100		99	99	99	98	108	108		110	110	110	108
235	0.78	No normal														
237	0.68	100	102	116		119	119		121	123	126	122	121	120	116	114
240	0.75	100	102	109	117	110	117	119	121	120	120	120	120		120	120
241	0.80	100	107	112	107		112	112	111	111	111	111	111	111	109	108
242	0.72	100		115		129	133	131	133	133	133	127	115	115	115	115
245	0.75	100		127	125	127	127	125	127	127	127	127	127	127	127	122
246	0.71	100	100	102	103		109	116	117	106	109	106	109	107	107	107
250	0.74	100	68	70	75	79	82	79	69	69	69	71	73	70	71	75
271	0.67	100	115	117		126	126	135	133	129	129	129	128	125	125	125
276	0.68	No normal														
Average			102	104	108	110	110	112	113	114	116	117	116	112	116	117

*D = died.

CLVIII

IN CHLORPICRIN POISONING

liter (91–110 parts per million)

Hours after exposure															
14	*15*	*16*	*17*	*18*	*19*	*20*	*21*	*22*	*23*	*24–26*	*26–30*	*30–36*	*36–42*	*42–48*	
	101		101		D*										
	101		101												
115	115	115	115	118	118	115	115	112		115	D				
174	179	174	174	174	171	178	171			174		177D			
117	125	125	125	125	131	137	137	137		138					D71 hrs.
135	138	134	138	139	140	143	141	124		142		177			
	111		112		114		114			105	98	91		99	
118		118		143			113			98	88	88		88	
96		121		113			102		99	121					
	108			106		99		111							
	126		126		116		128			122	110	93	87		
103		101		100		108		94		93		74	74		
123	119	123	123	123	124		124			121					
133	131	126	125	130		130		122		118					
159	157	157	155	153	147			147			148	145	131	131	
114	104	105	104	100	97	97	94			95					
102	102	99	99	98	101	102				101					
111	111	112	126	126	126	121	116			119					
120	122	125	120	120	120			120							
107	107	107	107	107	107	103	101	101		98					
115	115	115	115	110	110	110	110			100					
122	117	117	117	110	106	107				101					
103	102	102	102	102	102	100	100	100		101					
75	76	78	78	78	78	78		76							
124	121	121	118	118	118	118	115		118						
114	114	114	115	114	112	106	111	109	108	106	111	98	97	106	

TABLE

HEMOGLOBIN DETERMINATIONS

Concentration 0.81–0.95 mgm. per

Dog No.	*Conc.*	*Normal*	*Hours after exposure*													
			−1	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*
Acute Deaths																
210	0.95	100	134	147	154	151	205	D*								
12	0.90	100	85	97	114	112		133		D						
194	0.90	100		108	125			129	131	131D						
209	0.91	100	127	143	144	152	157		197	197	D					
63	0.95	100	159		154	150	174		166	176		171	194		D	
77	0.94	100	108			133	126		137	122		120				
62	0.93	100	132	139		141	143	161		140	156		152	178		178
218	0.83	100	114	122	139	152	174	174	174	177	182	168	182	185	182	182
189	0.89	100		102	99		102		97	97	103		111			
Average			123	123	133	141	154	149	150	149	147	153	160	181	182	180
Delayed Deaths																
217	0.89	100	115	116	124	124	125	140	146	132	138	141	132	141	141	141
207	0.92	100		80	90	87	98	98	96	97	98	98	120	121	120	120
215	0.85	100	118	118	121	130	145	154	160	160	162	164	161	158	158	155
196	0.91	100	104		112		123	131	128	128	135	137	143	145	145	137
Average			112	105	112	114	123	131	132	129	133	137	139	141	141	138
Recoveries																
17	0.95	100	81	81	97		91		105	107		106		111		105
64	0.95	100	130	148		145	150		157	158	150	165	180	185	191	
67	0.88	100	147	149	148	156		170	188		190		173		188	
106	0.87	100	113	118		106		120	121	130	138			137	128	
184	0.92	100	99	92	89	88	88	87	97	90	100	87	100	93	96	87
185	0.93	100	100	96	95	105	92	107	101	115	108	109	117	111	123	109
195	0.88	100	108		108	123		121	130	137	137	137		137	137	137
197	0.93	100		123		128	128	127	136	136	136	142	147	136	137	137
198	0.87	100					105	110	116	119	120	139	139	133	132	128
202	0.83	100		120	126		130		130	130	131	135	135	135	131	138
203	0.88	100		110	124		124	122	128	136	139	137	142	142	136	143
208	0.91	100	113	122	118	117	120	120	120	120	120	120	120	120	126	128
Average			111	116	113	121	114	120	127	125	134	123	139	125	139	125

* D = died.

CLIX

in Chlorpicrin Poisoning

liter (111–131 parts per million)

Hours after exposure															
14	*15*	*16*	*17*	*18*	*19*	*20*	*21*	*22*	*23*	*24–26*	*26–30*	*30–36*	*36–42*	*42–48*	
						D*									
	178		168			D									
186	186	188	165	152	159	167	D								
	106	113								D					
186	157	150	166	152	159	167									
160	145	160	154	143	133	136	143			136	139	141D			
120	120	120	120	120	116	120	115			118	117	133	D		
158	152	152	144	160	162	140	143			150	152	154	D		
136	136	134	136	130	128	126	130				150	150	150	151	D49 hrs.
143	138	141	138	138	135	130	133			135	139	144	150	151	
	114		111			88					78	78			
191		193		181		174			150		147				
187		188			176						168				
									145		113				
99	99	96	97	92							85				
121	131	127	125												
	128	125	125	128	119										
136	136	124	121	117	130	133					147	136	129	128	
128	128	122	125	122	116	112		119							
141	137	137	135	138	137	135	133	131		135	131				
142	145	139	143	139	136	136	136		136	132					
126	133		120	117	117			125			117	120	150	125	
141	128	139	122	129	133	130	135	125	144	134	123	111	140	126	

TABLE

Hemoglobin Determinations

Concentration 0.95–1.10 mgm. per

Dog No.	*Conc.*	*Normal*	*Hours after exposure*												
			−1	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*
Acute Deaths															
52	1.06	100	129	137	160	D*									
59	1.06	100	105	121		132	132D								
54	1.10	100		101	108	125		D							
15	1.02	100	105	119	125	125	128	D							
10	1.03	100	99	102	111	116	132	D							
65	0.98	100		127	151		144	D							
24	1.09	100	106	109	103		130	D							
40	1.04	100	105	116	133	126	154		D						
61	0.97	100	98	124		122	117	139		D					
57	1.07	100	88		103	129	125		140	139		D			
25	1.11	100		100	117		115	106	107		117	D			
14	0.97	100	137	137	158	157	147	155	151	144			D		
33	1.03	100			103	117	121	120	121		141	150		150	
44	1.03	100	101	118		118	117	126				157	157	145	
18	1.03	100	98	89		89		90	103		98		106		120
45	1.09	100	90		111	124	133				147	147	137		157
Average			105	115	124	123	130	123	124	142	126	131	133	147	138
Delayed Deaths															
50	1.05	100		123	119	139		139	125		154	149		146	163
66	0.96	100	93	92		95	95		95	115		128		114	
79	1.08	100	100		79	108		117		115					
55	1.09	100	113	130	163		163	172		165		185		183	
51	1.09	100	102	107	113		122	138		138	140		129	133	
11	1.07	100		116	124	135	140		159		177		157		157
Average			102	113	119	119	130	141	126	133	157	154	143	144	160
Recoveries															
19	0.97	100	93	96	106	101		112	116		106	106		92	83
20	1.05	100	98	92	96	100	121	124		124	114		104	96	
21	1.06	100	88	100	106	120	114	114	119		112	100		95	
46	1.06	No normal													
49	1.05	100	83	88	98			98	111		100		109		117
58	1.09	100	81	74	102		98	106	119		109	118		112	
75	1.00	100	111	99	105	104	111	97		111		113		107	
Average			92	91	102	106	111	108	116	118	108	109	106	100	100

* D = died.

CLX

in Chlorpicrin Poisoning

liter (131–153 parts per million)

Hours after exposure															
13	*14*	*15*	*16*	*17*	*18*	*19*	*20*	*21*	*22*	*23*	*24–26*	*26–30*	*30–36*	*36–42*	*42–48*
143		D *													
157		163		D											
	123		117			113	D								
	166	168	152		155		146	D							
150	145	166	134		155	113	146								
	172		159		160		162		168		D				
115		114		113			115				106	D			
												125	118	D	
161		170												D	
147		145		126		145		144		122		123	115	102	
	167		170		153			153				139	113	123	114D
141	169	143	164	119	156	145	138	148	168	122	106	193	173	114	114
	94		85		100		89		90		88		83	86	81
114		129		119				112			98	89		82	76
99		99		123		116		104			91				
	118		109		122		109				102		104	111	106
120		114		112		95		106			99			105	
								126		119					
111	106	114	97	118	111	106	99	112	90	119	96	89	93	96	88

TABLE

HEMOGLOBIN DETERMINATIONS

Concentration 1.11–1.25 mgm. per

Dog No.	*Conc.*	*Normal*	*Hours after exposure* −1	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*
Acute Deaths																
30	1.21	100	106	106	139		153D*									
26	1.16	100		114	146		154	135	D							
22	1.15	100	121	123	116	154	150		139	D						
60	1.18	100	136	137	164	168		168	197		D					
36	1.11	100	117	119	124		116	162		157		D				
32	1.19	100	113	112		120	126	126		143	159	D				
34	1.23	100	107	112	157	145	145	149		170	229		D			
28	1.23	100	101		112	119	147		139	134		157	D			
35	1.20	100		144	154	179		186	213		213		196		D	
38	1.11	100		86	91	92	92	110	111	108		106	103		D	
37	1.12	100	116		115	123	133	137	133		136	128		128	D	
41	1.15	100	113	107	127	124		126	128		126		151		158	
Average			114	116	131	136	135	144	150	142	175	130	150	128	158	
Delayed Deaths																
27	1.13	100	104	115		120	115	122	130		139	148		137		128
48	1.11	100	109				142	140	127		153		150		169	
47	1.22	100	108	123			155		160	163		157		198		163
39	1.11	100	108	111	120	129	132	142	135		141	135		131		139
23	1.16	100	94		114	119		119	109		106		114		114	
56	1.12	100	101	109	108		122		134		140	140	140		150	
16	1.14	100	104	113	104	110	110		110		121	116		124		109
Average			104	114	111	114	129	131	129	163	133	139	135	148	144	132
Recoveries																
29	1.25	100		102	103	96		131	129		132		125		118	
31	1.16	100	89	111	102	98	112	115	111	100		123			123	
42	1.15	100		115	122		128	129		135		129		162	157	
53	1.15	100	79	93		92	97	106		121	111		113		127	
Average			84	105	109	95	112	120	120	119	121	126	129	162	131	

* D = died.

CLXI

in Chlorpicrin Poisoning

liter (153–172 parts per million)

Hours after exposure															
14	*15*	*16*	*17*	*18*	*19*	*20*	*21*	*22*	*23*	*24–26*	*26–30*	*30–36*	*36–42*	*42–48*	
179		D*													
179															
	140		125		138			139			D				
144		147			160				139		D				
	172		198			154				155	155	D			
	145		168		172		159			125	127	D			
147		133		130							113	D			
133		122		115		116				134		102	D		
	114		121		146			114				89			D53 hrs.
141	143	134	153	122	154	135	159	126	139	138	131	96			
110		111				111			134			118		132	
116		127							122			112			
166		145		126		124				117		118	139	124	
123		111		115		118			110			106	101		
136		125		121		117			122	117		113	120	128	

APPENDIX

CHAPTER VII

Methods Employed

THE DOGS used in these experiments were healthy, full-grown animals which were gassed at definite concentrations of chlorine gas for a period of ½ hour. The blood for the erythrocytes and hemoglobin was obtained for the most part from the jugular vein. For the leucocyte count, blood was obtained from the ear veins. Blood smears for differential counts were stained with Wright's stain.

The erythrocytes were counted with a Thoma-Zeiss hemocytometer, using Hayem's solution to make the dilution (1 to 200). In estimating the number of leucocytes, a Thoma chamber was employed, thus affording the opportunity of counting 400 cm. Two such determinations were made, using 0.4% acetic acid to dilute the blood (1 to 20), and the average taken; the usual calculation was then made. The Gower's Haldane clinical method of hemoglobin determination was considered sufficiently accurate, two readings being made and the results averaged.

TABLE CLXII

Comparison of the Erythrocytes and Hemoglobin Content of Blood

Chlorpicrin Gas

Dog No.	*Date*	*Red Cell Count Normal*	*Hemo-globin*	*Gassed*	*Hours after Gassing*	*Red Cell Count after Gassing*	*Hemo-globin*	*Blood Count*	*Hemo-globin*
	1918			*mgm.*				*per cent*	*per cent*
286	10/26	7,320,000	125	1.029	1	9,600,000	168	132	134
	10/28	7,240,000	122		2	10,560,000	187	145	149
	10/29	7,280,000	125		3	10,800,000	192	148	154
					4	10,880,000	195	149	156
		7,280,000			5	10,040,000		138	
293	10/30	8,480,000	152	.990	½	8,640,000	152	101	100
					1	8,560,000	152	101	100
					2	8,640,000	152	101	100
					3	8,896,000	165	105	108
					4	8,960,000	168	106	110
					5	8,888,000	154	104	101
					6	9,540,000	178	112	117
					7	9,200,000	180	109	118
					8	9,460,000	184	111	118
					10	9,520,000	185	112	121
					12	9,320,000	186	110	122
					14	9,400,000	173	111	114
					16	8,992,000	165	106	108
					18		147		103
					20		138		91
					22	8,640,000	148	101	103
					24	8,720,000	146	103	102
					28	8,560,000	137	101	91
					32	7,600,000	126	90	83
311	11/4	7,936,000	117	1.299	1	6,896,000	114	87	98
		7,864,000	116		2	7,152,000	120	91	103
					4	8,064,000	126	102	108
		7,900,000	116		6	7,608,000	152	97	130
					8	7,608,000	162	99	138
					10	7,860,000	162	99	138
					12	8,800,000	162	111	138
					14	8,640,000	146	109	125

TABLE CLXIII

Comparison of the Erythrocytes and Hemoglobin Content of Blood

Chlorpicrin Gas

Dog No.	*Date*	*Red Cell Count Normal*	*Hemoglobin*	*Gassed*	*Hours after Gassing*	*Red Cell Count after Gassing*	*Hemoglobin*	*Red Count*	*Hemoglobin*
	1918			*mgm.*				*per cent*	*per cent*
308	11/2	7,088,000	110	.827					
		7,062,000			½	7,072,000	107	99	97
					1½	7,090,000	111	100	101
					2½	7,312,000	114	103	104
		7,075,000			3½	7,608,000	117	107	106
325	11/6	6,672,000	98	1.109	1	6,530,000	96	98	98
			98		3	7,208,000	111	109	113
					4	6,952,000	112	105	114
					5	9,690,000	117	145	120
					7	7,150,000	111	107	120
					9	8,400,000	114	125	116
					11	8,200,000	114	123	116
					15	8,944,000	114	132	116
					17	8,742,000	114	130	116
					19	7,940,000	114	119	116
					21	7,070,000	119	106	121
					25	8,810,000	119	131	121
								Blood Count	
332	11/7	6,240,000	111	1.166	1	7,416,000	126	118	113
					2	9,390,000	152	149	137
					3	9,430,000	171	151	154

D.

TABLE CLXIV

Comparison of the Erythrocytes and Hemoglobin Content of Blood

Chlorpicrin Gas

Dog No.	*Date*	*Red Cell Count Normal*	*Hemoglobin*	*Gassed*	*Hours after Gassing*	*Red Cell Count after Gassing*	*Hemoglobin*	*Red Count*	*Hemoglobin*
	1918			*mgm.*				*per cent*	*per cent*
356	11/21	8,270,000	111	.414	½	6,500,000	90	79	81
					1	7,880,000	94	96	85
					2	7,659,000	97	93	87
					3	8,260,000	104	95	94
					4	7,710,000	107	93	96
					5	7,040,000	99	85	89
					6	7,710,000	105	93	95
					8	8,086,000	109	97	98
					10	8,005,000	104	97	94
					20	8,600,000	117	104	106
					24	8,064,000	109	97	98
					28	8,020,000	106	97	97
362	11/23	5,980,000	111	.791	½	6,662,000	114	111	104
					1	7,260,000	123	121	112
					2	7,640,000	123	128	112
					3	9,360,000	140	157	127
					4	9,620,000	143	161	130
					6	9,440,000	147	158	134
					8	10,400,000	162	174	147
					10	10,530,000	167	176	152
					12	9,510,000	159	159	145
					20	10,006,000	152	168	138
					22	9,480,000	147	159	134
					28	7,460,000	122	125	111
					34	6,030,000	110	101	100
371	11/25	6,910,000	117	.731	½	7,320,000	126	106	108
					2	7,240,000	124	105	106
					3	7,780,000	137	113	117
					4	7,820,000	138	113	118
					5	8,580,000	146	124	125
					23	8,316,000	149	120	127
					27	7,850,000	140	114	119
					33	6,890,000	115	99	99

APPENDIX

CHAPTER XV

THE ADMINISTRATION OF OXYGEN TO GASSED DOGS

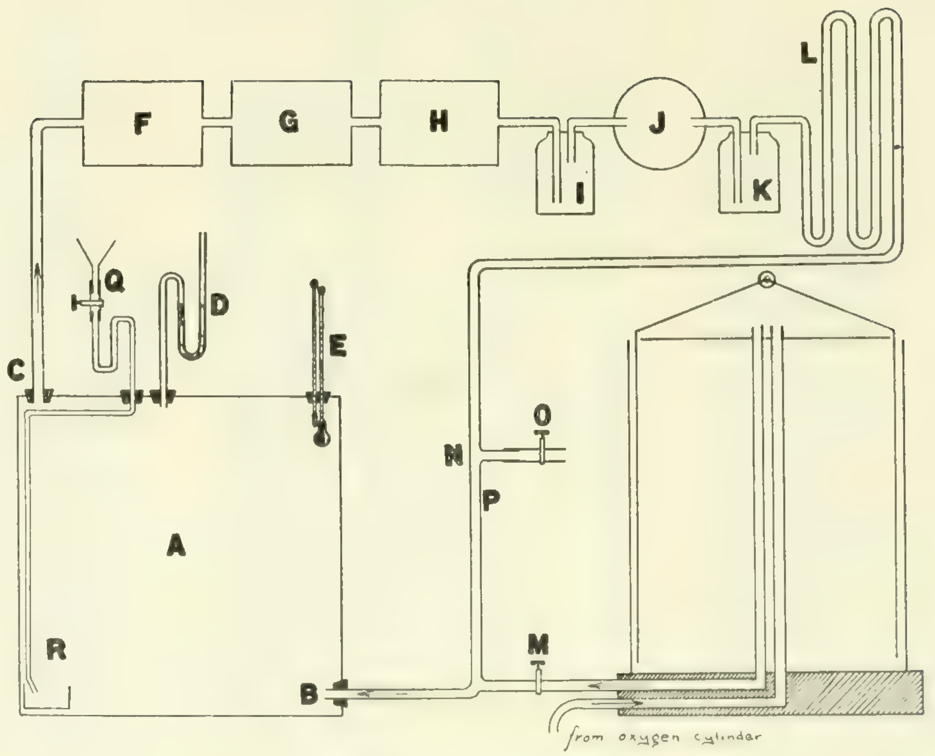
The Oxygen Apparatus

General description (see figure page 295). The oxygen chamber (A) is a glass box with a capacity of about 350 liters. The circulating air enters a box through a T-tube (B) near the bottom of the back wall and leaves it by a tube (C). A water manometer (D) indicates the pressure conditions in the box, a positive or negative pressure indicating a leak somewhere in the system. Wet and dry bulb thermometers (E) give data for calculating the relative humidity of the circulating air, which was kept between 0.754 and 0.928.

The air was circulated by a Crowell vacuum and blast pump, with a minute-capacity of about 50 liters, operated by a 110 volt, D.C. motor. After leaving the box by the tube (C) the air passed through an absorbing system consisting of three metal cartridges. The first of these (F) contained calcium chloride and charcoal for the absorption of water, the second (G) contained soda-lime for absorbing the expired carbon dioxide, while the third (H) again contained calcium chloride and charcoal for removing the water taken up from the moist soda-lime. The air then passed through a water-trap (I) designed to catch water which might collect in (H) and otherwise be sucked over into the pump (J), in case the calcium chloride became saturated. From the pump the air was blown through an oil-trap (K), for collecting the oil from the pump, thence through a system of glass coils, so arranged that on very hot days tap water dripped over them, being cooled by evaporation which was increased by a fan (in cooler weather the coils were disconnected), and finally back to the box. In the tube leading back to the box, a Y-tube was placed, so that oxygen could be introduced into the box from a spirometer. The tube leading from the spirometer was provided with a screw clip (M) so that it could be closed when oxygen was being added. At (N) another Y-tube was placed in the tube carrying the circulating air back to the box. This Y-tube opened to the outside at (O), the opening being kept closed except when a sample of the circulated air was desired for analysis, Orsat method, or when oxygen was being added.

The Administration of Oxygen

The procedure may be briefly described. The pump (J) having been started, the dog is placed in the box (A) and the front wall, which slides up and down, lowered and securely sealed with strips of adhesive plaster and with plasticene. The spirometer is then filled with oxygen from a cylinder. Clips (O) and (M) are opened and the tube leading to the box compressed at (P). The air in the box is then blown out at (O), and the negative pressure thus set up in the box sucks the oxygen from the spirometer. When the spirometer has been nearly emptied, the pressure on the tube at (P) is removed, and clips (O) and (M) closed simultaneously and the oxygen-enriched air then circulates in a closed system.



The Oxygen Apparatus.

Oxygen is gradually added in this way until its concentration in the circulating air reaches 50 per cent. Samples are taken, from time to time, and oxygen added as needed to keep up the concentration.

The dogs were placed in the circulating apparatus two to five hours after gassing, and kept there for 72 hours, three days having been shown to be the limit of the duration of the "acute stage" of poisoning. Water was given them by pouring it into the funnel (Q) from which it ran down into a glass vessel (R).

The Determination of Blood Oxygen in Dogs Gassed with Phosgene. Comparison while Breathing Air and Oxygen and the Influence of Venesection and Infusion

In the following pages are given the average findings with regard to the capacity, oxygen content of arterial and venous blood, while breathing oxygen as compared with while breathing air, before and after bleeding by 1 per cent of the body weight, and before and after infusion with an equal volume of warm, sterile isotonic physiological salt solution (0.95 per cent). A comparison of the results obtained with dogs gassed at the concentration 50–60 parts per million (0.21–0.26 mgm. per liter) is made with those obtained after gassing at 70–80 parts per million (0.30–0.35 mgm. per liter). Blood gases were determined by the method of Henderson and Smith (Journ. Biol. Chem. 1917–18, xxxiii, page 39).

The dogs are divided into four series as follows:

1. Series 3, ten dogs (see Table CLXV, page 299) Phosgene 70-80. All dogs bled, five of which were infused.
2. Series 4, twelve dogs (see Table CLXVI, page 302) Phosgene 50-60. All dogs bled, six of which were infused.
3. Series 5, seven dogs (see Table CLXVII, page 305) Phosgene 70-80. All bled and infused.
4. Series 6, four dogs (see Table CLXVIII, page 308) Phosgene 50-60. All bled and infused. In series 5, ten samples of blood were drawn on the same day, and in addition to the loss of blood, the animal had to be kept on the table for long periods. Series 6 was run to check the findings in the later periods, a minimal number of blood samples being taken for the early periods, a sufficient amount of data having already been acquired in the earlier series.

Capacity

It may seem hardly necessary to say anything more about this factor, but perhaps corroborative evidence will not be out of place here. In series 3 (Phosgene 70–80) in nine cases one-half to one and one-half hours after gassing the capacity showed an average drop of 3.3 per cent. In series 4 (Phosgene 50–60) the capacity fell an average of 1.5 per cent, the samples being taken an average of forty-six minutes after gassing. In series 5 (Phosgene 70-80) the capacity showed an average drop of 3.44 per cent, the samples being taken an hour after gassing.

Venesection

In series 3 (Phosgene 70–80) nine cases after bleeding showed an average rise of 0.8 per cent, the samples being taken an average of forty-two minutes after bleeding, and one hour and forty-six minutes after gassing. In series 4 (Phosgene 50–60) the capacity in eight dogs fell 0.26 per cent, the average time of drawing blood samples being thirty-five minutes after gassing or two hours and two minutes after gassing. In series 5 (Phosgene 70–80) six out of the seven dogs showed an increase in capacity, averaging 1.3 per cent, the samples having been drawn twenty-five minutes after bleeding and two hours and five minutes after gassing. Thus in both series gassed at the higher concentrations, the capacity rose after bleeding, while in the series gassed at the lower concentrations, the capacity either remained the same or fell slightly.

Infusion

In series 3 (Phosgene 70–80) of the five dogs infused, four showed an average rise in capacity of 0.32 per cent, samples being taken an average of twenty-five minutes after infusion; the other dog showed a decrease of 0.7 per cent. In series 4 (Phosgene 50–60) after infusion, six dogs showed a decreased capacity, average drop of 1.55 per cent, samples being taken twenty-two minutes after infusion. One dog again showed a slight rise. In series 5 (Phosgene 70–80) following infusion the capacity fell in every case, averaging a drop of 2.06 per cent, samples taken eleven minutes after infusion or seven hours and twelve minutes after gassing. In series 6 (four dogs, Phosgene 70–80) the capacity dropped 1 per cent after infusion, the samples being taken an average of sixteen minutes after infusion, or six hours and fifty minutes after gassing.

In all of these series ten dogs survived until the following day. Of these seven eventually recovered, three dying within three days after gassing. In the case of the recoveries, the capacity was slightly subnormal. The capacity of the dogs that died showed a considerable variation from normal, two being an average of 2.2 per cent above, and the other 3.09 per cent below.

ARTERIAL AND VENOUS OXYGEN CONTENT

WHEN BREATHING AIR AND WHEN BREATHING OXYGEN

The average normal percentage saturations of arterial and venous blood in series 4 were almost identical with those of series 5 (series 4 — Arterial Saturation 90.2, Venous Saturation 50.9; series 5 — Arterial Saturation 91.2, Venous Saturation 50.4).

Breathing Air after Gassing

(*Average Time, Thirty-seven Minutes*)

In series 4 and 5 both arterial and venous percentage saturation fell after gassing; although the capacity was falling at this period (see Capacity), both arterial and venous content fell relatively more, so that the percentage saturation decreased. In series 5 (Phosgene 70–80) the arterial saturation fell from 91.2 per cent to 74.75 per cent, a drop of 16.45 per cent. In series 4 (Phosgene 50–60) the drop in saturation was only 45 per cent of that in series 5. In series 5 (Phosgene 70–80) the venous percentage saturation fell from 50.45 per cent to 32.23 per cent, a drop of 18.22 per cent. In series 4 (Phosgene 50–60) the decrease was 80 per cent of that in series 5. In both series the fall in venous percentage saturation was relatively and actually greater than that in arterial saturation.

Breathing Oxygen after Gassing
(*Average Time, One Hour and Six Minutes*)

When the dogs were given oxygen (50 per cent) at this period a rise in the arterial and venous percentage saturation was obtained in the large majority of cases, as has been noted above, and as seen in the various tables. The time at which oxygen was given permits of direct comparison only in series 5 (Phosgene 70–80). Here there was an average rise of 10.65 per cent in the arterial saturation, and 4.52 per cent in the venous.

Breathing Air Again after Breathing Oxygen
(*Average Time, One Hour and One Hour and Thirty-seven Minutes*)

The arterial saturation fell, and has an average value 4.25 per cent lower than the figure when the dogs were breathing air before being given oxygen. The venous saturation usually returned to the previous value for air.

VENESECTION

Breathing Air
(*Average Time (Series 5) Two Hours and Five Minutes after Gassing*)

In series 4 (Phosgene 50–60), partly owing to a slight drop in capacity (and a slight rise in the arterial content) the arterial percentage saturation rose an average of 8 per cent. The percentage saturation of the venous blood remained practically the same (the venous content running parallel to the capacity). In series 5 (Phosgene 70–80) the arterial percentage saturation fell, an average of 1 per cent. As was noted above, under Capacity, in this series the capacity rose 1.3 per cent after bleeding. The venous content remained practically the same, and therefore the percentage saturation dropped about 3 per cent.

Period before Infusion (after Venesection)

Breathing air. In series 5 (Phosgene 70–80) five and one-half hours after gassing. In series 6 (Phosgene 70–80) four hours and forty-eight minutes after gassing.

In series 5 the arterial percentage saturation is an average of 11.5 per cent above the value obtained when the dogs are breathing air just after bleeding. This is due in part to the increase in capacity, but also to the relatively greater increase in content, as is also indicated by the greater oxygen consumption at this time. On the other hand the venous percentage saturation showed an average decrease of 2 per cent. Due to the fact that the venous content on the average has remained the same, and since the capacity is higher, the percentage saturation of the venous blood is therefore lower. In series 6 (also at 70–80) the arterial saturation rose to 95 per cent, an increase of 8 per cent over the value obtained at the time of bleeding. Venous saturation again fell 2 per cent, the content remaining about the same.

Breathing oxygen. Average time, series 4 (Phosgene 50–60) four to six hours after gassing; series 5 (Phosgene 70–80) five hours and fifty-three minutes after gassing; series 6 (Phosgene 70–80) five hours and twenty-four minutes after gassing.

In series 4, in every case, the arterial and venous percentage saturation rose, due to the increased oxygen content. The arterial percentage saturation was thus raised 2 per cent above the normal, but the venous percentage saturation, in spite of a 15 per cent rise, was still 11 per cent below normal. In two cases only the venous saturation rose above normal. In series 5 (Phosgene 70-80) a rise in arterial percentage saturation occurred in all cases, four dogs showing 100 per cent saturation, the average being 98.5 per cent. The venous percentage saturation was also raised an average of 8 per cent, attaining the average value of 34.7 per cent. In series 6 (Phosgene 70-80) the arterial percentage saturation was raised to 99.0 per cent, the venous to 53.3 per cent.

INFUSION

Breathing air. Average time, series 5 (Phosgene 70–80) twenty-two minutes after infusion, and six hours and fifty minutes after gassing; series 6 (Phosgene 70–80) sixteen minutes after infusion, and six hours and thirty-four minutes after gassing.

Infusion is invariably followed by a marked drop in the capacity. In series 4, the arterial and venous content were lower relatively, so that even with the reduced capacity, the arterial and venous percentage saturation were, when the dogs were breathing air, lower after infusion than before infusion. In contrast to the arterial content, the venous content rose (although the capacity was decreasing) an average of 1.2 per cent, producing an average rise of 9.62 per cent in the venous saturation.

Infusion may, therefore, be said to have a decidedly beneficial effect in this connection, as indicated by the fact that the venous blood carries more oxygen.

Breathing oxygen. Average time, series 5 (Phosgene 70–80) forty-five minutes after infusion; series 6 (Phosgene 70–80) thirty-six minutes after infusion.

Following the drop in the capacity soon after infusion, there is a rise. In series 4 (Phosgene 50–60) while breathing oxygen, complete arterial saturation occurred in four out of six cases, in contrast to series 5 (Phosgene 70–80) where complete saturation was not reached, although three cases reached 96 per cent. In series 6 (Phosgene 70–80) the highest average percentage saturation was reached, namely 97.7 per cent, two of the four dogs reaching complete saturation.

The average venous saturation in series 4 (Phosgene 50–60) was 29.21 per cent, being 7.5 per cent higher than in series 5 (Phosgene 70–80). In series 6 (Phosgene 70–80) the average venous saturation reached the high figure of 48 per cent, the average rise being 5 per cent. In series 5 (Phosgene 70–80) a marked drop in venous saturation occurred in four dogs. This was due to the fact, mentioned above, of the experiments being long in duration, many samples having been drawn, and the consequent weakened condition of the animals.

A number of the dogs were studied the day after gassing in order to determine the saturation of the arterial and venous blood with oxygen. In series 6 it was found, while the animals were given oxygen, that the arterial blood was practically saturated, — 98 per cent. The venous percentage saturation showed a greater rise than was caused by the administration of oxygen the day previously after infusion, being raised from 29.7 to 45.7 per cent. The arterial and venous saturation breathing air returned to the value found before the giving of oxygen.

TABLE CLXV

(Series 3)

THE INFLUENCE OF OXYGEN ADMINISTRATION UPON THE PERCENTAGE SATURATION AND OXYGEN CONTENT OF THE BLOOD OF DOGS GASSED WITH PHOSGENE

(70–80 parts per million) (0.30–0.35 mgm. per liter)

No.	*Time*	*Capacity*	*Arterial content*	*Venous content*	*Arterial percentage saturation*	*Venous percentage saturation*	*Hemoglobin*	*Remarks*
147	11.40	19.8	18.9	12.3	95.0	62.0	100	Normal, breathing air 9/3
								Gassed, 9.16 A.M. 9/4
								Bled 1% body weight 11.05
	11.00	16.8	14.7	9.7	87.0	57.0	120	breathing air
	11.30	17.4	15.0	4.3	86.0	24.0	130	“ “
	2.45	18.1	18.7	8.3	100.0	45.0	130	“ oxygen
	3.30	21.3	14.4(?)	7.2	67.0	33.0	130	“ “
	4.20	21.3	16.4	0.9	77.0	4.2	130	“ air
	9.25	22.6	12.8	2.2	56.0	9.7	130	“ “ 9/5
	9.50	20.8	17.8	6.5	85.0	31.0	130	“ oxygen
	10.20	21.1	18.0	1.4	85.0	6.6	130	“ “
	10.45	21.4	6.1	0.0	28.0	0.0	130	“ air
150	2.30	14.4	13.0	0.7	92.0	48.5		Normal, breathing air 9/5
								Gassed, 10.11 A.M. 9/6
	10.45	12.1	6.7	0.8	55.0	6.6	100	breathing air
								Bled 1% body weight 11.20
	11.55	11.7	3.0	0.7	25.0	5.9	100	breathing air
	2.35	13.5		2.8		20.0	100	“ “
	3.10	13.6	11.7	3.9	86.0	28.6	110	“ oxygen (pure)
	3.30	15.0	14.7		98.0		110	“ “
	4.05	14.5	11.8	6.0	81.4	41.4	120	“ air
	8.40	19.0	9.5	9.0	50.0	0.0	110	“ “ 9/7
	9.08	18.0	12.7	0.6	70.0	4.7	110	“ oxygen
	9.30	18.0	8.7	1.2	48.0	13.0	110	“ “
	10.10	17.0	5.2	0.0	30.0	0.0	110	“ air
153	9.15	17.5	16.5	9.2	94.0	52.0	120	Normal, breathing air 9/9
								Gassed, 1.50 P.M.
	2.50	12.2	13.9	6.1	100.0	50.0	100	breathing air
								Bled 1% body weight 2.55 P.M.
	4.00	14.6	11.3	4.2	77.0	28.0	110	breathing air
	9.10	18.7	14.5	2.4	77.0	9.0	130	“ “
	9.50	18.9	19.3	1.7	100.0	9.0	130	“ oxygen
	10.45	19.1	14.8	1.9	77.0	10.0	130	“ air
	11.20	19.2	16.8	2.9	87.0	15.0	140	“ oxygen
	11.45	19.3	15.5	3.7	80.0	19.0	130	“ air
	9.30	11.1	8.3	2.7	75.0	24.0	120	“ “ 9/11
	10.20	11.5	12.1	3.9	100.0	34.0	110	“ oxygen
	11.10	11.7	8.8	1.6	75.0	14.0	110	“ air
	11.30	11.5	11.3	4.8	98.0	42.0	120	“ oxygen
	11.50	11.4	8.4	2.6	74.0	23.0	110	“ air

TABLE CLXV (Continued)

No.	*Time*	*Capacity*	*Arterial content*	*Venous content*	*Arterial percentage saturation*	*Venous percentage saturation*	*Hemoglobin*	*Remarks*
157	3.30	18.5	16.3	5.7	88.0	34.0	130	Normal, breathing air 9/11
								Gassed, 9.14 A.M. 9/12
	10.10	15.6	14.8	2.5	95.0	19.0	110	breathing air
								Bled 1% body weight 10.15 A.M.
	11.00	18.3	15.4	5.0	84.0	27.0	120	breathing air
	11.23	16.7	16.7	7.6	100.0	46.0	130	“ oxygen
	2.10	21.1	17.1	3.6	85.0	17.9	130	“ air
								Infused 1% body weight 3.25 P.M.
	3.45	21.2	16.4	5.8	82.0	29.0	120	breathing air
	4.20	20.7	20.3	6.4	98.0	31.0	130	“ oxygen
	4.45	19.3	13.5	0.7	70.0	15.0	130	“ air
158	3.30	12.2	12.1	7.7	99.3	63.5	95	Normal, breathing air 9/12
								Gassed, 8.59 A.M. 9/13
	9.20	8.8	8.0	1.2	91.0	14.0	110	breathing air 9/13
								Bled 1% body weight 9.55 A.M.
	10.25	8.2	8.9	1.7	100.0	20.0	70(?)	breathing air
	1.20	8.5	7.1	1.1	83.0	13.0	100	“ “
	3.10	11.3						“ “
	4.10	13.9	14.2	3.7	100.0	27.0	90	“ oxygen
								Infused 1% body weight 4.40 P.M.
	4.58	14.5	10.8	1.7	74.5	8.5	95	breathing air
	5.25	13.0	12.2	6.5	94.0	50.0	90	“ oxygen
	5.45	13.5	11.9	0.0	88.2	0.0	90	“ air
162	10.00	15.6	15.2	6.0	97.5	38.6	130	Normal, breathing air 9/16
								Gassed, 8.49 A.M. 9/17
	9.15	13.4	11.8	5.1	88.0	38.0	110	breathing air
								Bled 1% body weight 9.50 A.M.
	10.30	14.8	12.8	2.7	86.6	18.3	110	breathing air
	11.10	14.3	14.3	5.6	100.0	39.2	110	“ oxygen
	11.30	15.3	13.7	5.7	89.5	37.2	110	“ air
	2.30	18.9	17.6	6.1	90.1	32.3	125	“ “
								Infused 1% body weight 3.05 P.M.
	3.30	18.2	13.8	2.3	76.0	11.3	110	breathing air
	4.10	20.1	20.1	11.7	100.0	58.3	110	“ oxygen
	4.50	20.6	15.5	3.2	75.4	15.5	120	“ air

TABLE CLXV (Continued)

No.	Time	Capacity	Arterial content	Venous content	Arterial percentage saturation	Venous percentage saturation	Hemoglobin	Remarks
163	2.25	18.8	18.9	8.9	100.0	47.0	130	Normal, breathing air 9/16
								Gassed, 8.42 A.M. 9/18
	9.20	15.2	12.0	3.8	79.0	25.0	120	breathing air
								Bled 1% body weight 9.50 A.M.
	10.15	13.2	13.1	4.3	100.0	32.6	120	breathing air
	11.00	16.1	16.5	11.0	100.0	68.4	110	“ oxygen
	11.15	13.3(?)	14.1	1.5	100.0	11.3	110	“ air
	2.45	16.5	14.9	4.7	90.5	28.4	110	“ “
								Infused 1% body weight 3.20 P.M.
	4.00	16.8	13.2	4.3	78.6	25.6	110	breathing air
	4.25	17.1(?)	18.6	7.9	100.0	46.2	110	“ oxygen
	5.00	15.2	13.8	5.7	91.0	37.5	110	“ air
167	2.15	24.2	23.7	8.4	98.0	34.7	130	Normal, breathing air 9/19
								Gassed, 8.42 A.M. 9/20
	9.15	17.8	15.6	7.7	87.6	43.3		breathing air
								Bled 1% body weight 10.05 A.M.
	10.35	20.1	18.7	8.2	93.0	40.8		breathing air
	11.20	20.4	21.8	8.4	100.0	41.0		“ oxygen
	11.45	20.8	21.1	5.6	100.0	28.0		“ air (?)
	2.00	24.0	24.5	0.8	100.0	41.5	135	“ “ (?)
								Infused 1% body weight 3.00 P.M.
	3.20	24.3	22.4	12.4	88.0	50.0	130	breathing air
	4.05	27.5	27.5	5.9	100.0	21.6	130	“ oxygen
	4.25	25.7	24.7	8.3	92.5	32.3	140	“ air

TABLE CLXVI

(Series 4)

The Influence of Oxygen Administration upon the Percentage Saturation and Oxygen Content of the Blood of Dogs Gassed with Phosgene

(50–60 parts per million) (0.21–0.26 mgm. per liter)

No.	*Time*	*Capacity*	*Arterial content*	*Venous content*	*Arterial percentage saturation*	*Venous percentage saturation*	*Hemoglobin*	*Remarks*
174	1.30	16.7	15.5	7.1	92.8	42.5	90	Normal, breathing air 9/26
								Gassed, 9.02 A.M. 9/27
	9.20	16.3	14.4	6.5	88.4	39.8	110	breathing air
								Bled 1% body weight 10.20 A.M.
	11.00	15.9	15.2	5.2	95.5	32.7	110	breathing air
	11.20	17.7	17.7	12.2	100.0	68.9	110	" oxygen
	11.35	17.9	15.4	5.2	86.0	29.0	110	" air
	2.15	18.2	17.6	6.0	96.7	32.0	110	" "
								Infused 1% body weight 3.20 P.M.
	3.45	18.6	17.7	6.1	95.1	32.8	110	breathing air
	4.00	18.4	19.7	6.1	100.0	33.2	110	" oxygen
	4.30	18.2	16.6	3.9	91.2	21.4	130	" air
	9.45	18.5	14.1	0.76	76.2	4.0	120	" " 9/27
	10.05	16.2	15.7	0.32	97.2	1.9	120	" oxygen
	10.25	17.3	10.4	0.22	60.2	1.3	125	" air
177	9.00	21.5	16.6	13.3	77.2	62.4	118	Normal, breathing air 9/30
								Gassed, 1.44 P.M.
	3.00	19.7	14.8	7.1	75.0	36.0	125	breathing air
								Bled 1% body weight 3.35 P.M.
	3.55	19.6	16.3	12.9	83.2	65.4	130	breathing air
	4.30	21.1	21.5	16.6	100.0	78.8		" oxygen
	4.50	18.6	16.8	6.4	90.4	34.4		" air
	10.15	24.1	17.3	5.6	71.8	23.2	125	" " 10/1
	10.45	24.0	21.7		90.4		135	" oxygen
178	10.20	18.6	17.3	11.4	93.0	61.5		Normal, breathing air 9/30
								Gassed, 8.55 A.M. 10/1
								Bled 1% body weight 10.30 A.M.
	2.26	16.8	14.6	6.2	87.0	36.8	120	breathing air
	3.10	17.0	17.5	10.6	100.0	62.5	130	" oxygen
								Infused 1% body weight 4.10 P.M.
	4.30	16.6	16.6	1.7	100.0	6.2	130	breathing air
	4.50	18.3	18.3	3.6	100.0	19.7	130	" oxygen
	5.25	19.2	19.1		99.0		135	" air
	9.45	18.4	16.1	1.5	87.5	8.2	130	" " 10/2
	10.30	17.4	12.5(?)	6.6	71.9(?)	37.9	125	" oxygen
	11.15	16.4	14.2	1.4	86.5	8.6	135	" air

TABLE CLXVI (Continued)

No.	*Time*	*Capacity*	*Arterial content*	*Venous content*	*Arterial percentage saturation*	*Venous percentage saturation*	*Hemoglobin*	*Remarks*
181	2.00	23.4	19.0	11.4	81.4	49.0	135	Normal, breathing air 10/2
								Gassed, 1.52 A.M. 10/3
	2.30	22.8	16.3	9.3	71.5	40.6	135	breathing air
								Bled 1% body weight 3.00 P.M.
	4.15	21.0	17.1	4.3	81.2	20.7	135	breathing air
	9.30	27.2	19.4	2.6	71.0	7.5	140	" " 10/4
	10.25	26.5	25.9	4.6	97.8	17.3	140	" oxygen
	11.10	26.0	12.8	1.2	49.2	4.8	140	" air
182	2.30	17.0	15.4	7.4	90.6	43.3	125	Normal, breathing air 9/30
	2.15	13.4	12.4	8.3	92.2	61.8	130	" " " 10/2
								Gassed, 9.11 A.M. 10/4
								Bled 1% body weight 10.15 A.M.
	8.30	17.0	9.4	0.79	55.2	4.6	140	breathing air 10/5
	9.30	19.2	16.7	0.32	87.2	1.6	135	" oxygen
								Infused 1% body weight 9.50 A.M.
	10.25	18.2	7.1	0.48	39.3	8.1	135	breathing air
	10.45	17.2	13.2	0.42	77.0	8.2	140	" oxygen
	11.30	18.0	5.4	0.25	29.8	1.4	135	
185	9.00	21.1	16.8	9.2	79.8	43.5	150	Normal, breathing air 10/7
								Gassed, 1.38 P.M. 10/7
	2.20	19.5	17.0	11.4	87.2	58.1	140	breathing air
								Bled 1% body weight 3.00 P.M.
	4.00	19.8	17.1	8.1	86.7	41.2	145	breathing air
	9.00	24.4	23.8	8.1	97.5	36.1	155	" "
	2.30	23.3	19.5	6.9	91.5	29.9	155	" "
								Infused 1% body weight 4.00 P.M. 10/8
	4.10	21.3	17.7	7.6	78.5	35.7	155	breathing air
	9.00	19.2	18.2	3.8	94.8	19.6	155	" "
189	10.00	12.2	10.5	4.9	86.1	40.0	130	Normal, breathing air 10/10
								Gassed, 8.50 A.M. 10/11
	9.20	10.8	7.3	2.8	68.0	26.0	130	breathing air
								Bled 1% body weight 10.05 A.M.
	10.25	10.0	9.1	1.0	90.8	10.4	130	breathing air
	2.15	12.2	10.5	0.9	86.6	7.2	130	" "
	3.50	11.7	9.2	1.5	78.6	12.4	145	" "
	4.20	11.0	9.8	1.8	89.0	16.0	110	" oxygen
	5.05	11.6	10.1	0.6	86.4	4.9	130	" air
								Infused 1% body weight 5.25 P.M.
	5.55	9.6	8.3	0.2	86.2	2.2	130	breathing air
	6.45	12.4	13.0	0.0	100.0	0.0		" oxygen
	9.30	11.0	8.6	0.7	78.0	6.6	135	" air

TABLE CLXVI (Continued)

No.	*Time*	*Capacity*	*Arterial content*	*Venous content*	*Arterial percentage saturation*	*Venous percentage saturation*	*Hemoglobin*	*Remarks*
192	9.05	20.4	19.4	10.8	94.8	52.8	160(?)	Normal, breathing air 10/13
								Gassed, 8.58 A.M. 10/14
	9.30	18.5	17.2	2.2	93.3	12.1	160	breathing air
								Bled 1% body weight 10.30 A.M. 10/15
	10.30	15.8	14.3	5.1	90.0	31.9	150	breathing air
	2.40	18.1	16.1		88.9		135	" "
	3.40	16.6	15.3		92.0		140	" "
	7.00	16.3	17.0		95.5			" "
	11.00	17.7	14.1	2.6	80.0	14.7	135	" "
194	1.45	20.9	20.1	14.5	96.4	70.0	130	Normal, breathing air 10/16
								Gassed, 8.58 A.M. 10/17
	11.05	17.2	15.1	8.0	87.8	46.6	110	breathing air
								Bled 1% body weight 11.15 A.M.
	11.40	20.6	20.4	12.5	99.0	60.6		breathing air
	3.40	19.6	17.5	5.4	89.4	27.1	125	" "
	4.55	21.7	22.1	13.0	100.0	60.2	125	" oxygen
								Infused 1% body weight 5.15 P.M.
	5.25	17.4	15.6	5.8	90.0	33.3		breathing air
	6.00	20.1	19.4	10.1	95.8	50.0	130	" oxygen
	7.00	20.2	17.6	7.2	86.2	35.6	140	" air
	10.30	18.9	16.0	6.8	85.0	36.2	135	" " 10/18
	11.15	20.7	19.7	8.2	95.5	39.9	150	" oxygen

TABLE CLXVII

(Series 5)

The Influence of Oxygen Administration upon the Percentage Saturation and Oxygen Content of the Blood of Dogs Gassed with Phosgene

(70–80 parts per million) (0.30–0.35 mgm. per liter)

No.	*Time*	*Capacity*	*Arterial content*	*Venous content*	*Arterial percentage saturation*	*Venous percentage saturation*	*Hemoglobin*	*Remarks*
196	9.00	19.5	17.4	10.9	89.1	56.2	140	Normal, breathing air 10/18
								Gassed, 9.36 A.M. 10/21
	10.25	17.7	16.1	6.2	91.0	35.0	150	breathing air
								Bled 1% body weight 11.15 A.M.
	11.40	18.8	14.9	8.9	79.4	47.5	135	breathing air
	4.40	18.5	17.7	6.3	95.6	33.9	135	“ “
	5.15	18.0	21.4	5.1	100.0	28.5	130	“ oxygen
								Infused 1% body weight 5.55 P.M.
	6.30	21.0	20.2	10.0	96.1	47.6	130	breathing oxygen
	7.15	21.0	15.8	9.4	75.0	44.7	130	“ air
	10.30	21.3	14.3	1.8	66.9	5.1	145	“ “ 10/22
	10.55	20.0	19.6	3.7	98.0	18.6	140	“ oxygen
	11.30	18.3	14.5	1.4	79.2	7.8	140	“ air
198	2.00	13.7	12.9	6.1	94.3	44.4	95	Normal, breathing air 10/22
								Gassed, 9.05 A.M. 10/23
	10.00	12.7	8.4	2.1	66.4	16.8	90	breathing air
	10.30	12.5	11.0	4.3	87.7	34.3	90	“ oxygen
	10.50	12.1	8.4	2.8	69.5	23.1	70(?)	“ air
								Bled 1% body weight 11.00 A.M.
	11.35	11.9	9.9	2.8	83.1	23.9	90	breathing air
	3.10	13.5	8.9	1.8	66.6	13.1	90	“ “
	3.50	15.1	11.6	5.9	88.0	39.4	85	“ oxygen
	4.20	14.0	8.2	0.3	58.5	2.0	70	“ air
								Infused 1% body weight 1.05 P.M.
	5.15	13.4	4.1	0.2	31.8	1.6	70	breathing air
	5.29	19.3	8.8	0.3	45.6	1.4	70	“ oxygen
	5.50	11.4	1.1		9.5			“ air

TABLE CLXVII (Continued)

No.	*Time*	*Capacity*	*Arterial content*	*Venous content*	*Arterial percentage saturation*	*Venous percentage saturation*	*Hemoglobin*	*Remarks*
199	9.55	21.2	19.8	10.2	93.5	48.2	150	Normal, breathing air 10/24
								Gassed, 8.55 A.M. 10/25
	9.25	16.1	12.9	7.3	81.0	45.5	130	breathing air
	10.00	17.2	17.1	9.3	99.0	54.1	135	" oxygen
	10.35	16.6	12.6	6.3	75.9	37.9	135	" air
								Bled 1% body weight 10.45 A.M.
	11.00	17.7	13.8	2.6	78.2	14.9	130	breathing air
	2.05	18.6	17.2	7.4	87.7	39.5	135	" "
	2.45	21.2	21.0	3.9	99.9	18.5	135	" oxygen
	3.15	20.2	18.3	2.1	91.0	10.6	135	" air
								Infused 1% body weight 4.08 P.M.
	4.15	15.4	15.0	4.5	97.5	29.5	130	breathing air
	4.38	21.5	20.4	2.5	94.9	11.5	135	" oxygen
	5.05	18.9	13.8	0.2	72.8	11.3	140	" air
200	8.55	20.6	18.4	10.6	89.3	51.7	135	Normal, breathing air 10/26
								Gassed, 10.01 A.M. 10/28
	10.30	14.6	10.8	5.6	73.6	38.2	130	breathing air
	11.04	14.1	11.3	7.2	80.0	50.9	135	" oxygen
	11.25	14.8	10.0	6.2	67.4	41.4	135	" air
								Bled 1% body weight 11.28 A.M.
	11.55	16.1	9.3	6.6	57.8	40.7	135	breathing air
	2.30	19.3	15.6	8.1	81.0	42.0	130	" "
	2.50	19.6	17.9	11.4	91.5	58.4	135	" oxygen
	3.25	19.6	16.4	0.2	83.6	1.2	138	" air
								Infused 1% body weight 3.50 P.M.
	4.00	19.2	14.1	5.8	73.5	30.0	140	breathing air
	4.20	19.8	16.2	8.8	82.0	44.8		" oxygen
	4.45	20.3	14.4	2.2	71.0	10.9	135	" air
201	10.25	12.6	12.2	2.7	80.6	21.6	80	Normal, breathing air 10/29
								Gassed, 8.54 A.M. 10/30
	9.30	10.9	7.4	1.1	68.1	9.9		breathing air
	10.03	9.2	8.7	0.6(?)	94.3	6.8(?)	90	" oxygen
	10.35	10.7	5.1	1.2	48.1	11.2	85	" air
								Bled 1% body weight 10.45 A.M.
	11.12	11.9	7.6	1.7	63.5	14.3	80	breathing air
	2.20	13.5	11.4	0.2	84.9	1.6	95	" "
	3.00	13.5	14.1	1.1	100.0	8.1	95	" oxygen
	3.50	12.9	9.5	0.1	73.7	1.2	95	" air
								Infused 1% body weight 4.07 P.M.
	4.17	9.7	6.8	1.7	70.3	17.4	90	breathing air
	4.30	11.6	10.2	0.1	87.4	10.3	90	" oxygen
	4.45	12.4	6.6	0.2	53.5	1.2	85	" air

TABLE CLXVII (Continued)

No.	*Time*	*Capacity*	*Arterial content*	*Venous content*	*Arterial percentage saturation*	*Venous percentage saturation*	*Hemoglobin*	*Remarks*
204	10.00	15.0	13.6	8.9	90.0	59.9	135	Normal, breathing air 10/31
								Gassed, 8.56 A.M. 11/1
	9.55	14.2	11.9	5.3	83.6	37.6	135	breathing air
	10.33	16.1	12.8	3.3	79.7	24.1	130	“ oxygen
	10.55	15.9	14.0	4.6	88.6	29.2	130	“ air
								Bled 1% body weight 11.02 A.M.
	11.15	16.8	12.0	3.6	71.5	21.2	130	breathing air
	2.30	16.9	16.8	2.5	99.9	14.9	130	“ “
	3.30	16.5	16.5	5.2	99.9	31.4	130	Infused 1% body weight 4.30 P.M.
	4.40	16.0	14.4	5.8	90.1	36.1	135	breathing air
	4.57	16.7	15.7	5.8	94.0	34.8	130	“ oxygen
	5.25	17.4	14.5	0.8	83.7	4.3	130	“ air
206	9.20	19.9	19.1	12.9	96.0	65.0	140	Normal, breathing air 11/2
								Gassed, 9.50 A.M. 11/3
	10.30	15.8	8.8	5.3	55.8	33.7	130	breathing air
	10.48	14.6	13.7	6.1	94.0	41.6	130	“ oxygen
	11.22	14.9	9.7	6.8	65.5	40.3	130	“ air
								Bled 1% body weight 11.23 A.M.
	11.35	15.9	7.6	5.7	47.7	35.7	130	breathing air
	2.25	18.3	7.5	6.1	40.8	33.1	135	“ “
	2.55	17.6	16.8	9.0	95.5	50.7	130	“ oxygen
	3.30	18.2	15.1	1.7	83.3	9.2	130	“ air
								Infused 1% body weight 3.50 P.M.
	4.10	15.1	10.5	0.8	69.3	5.5	135	breathing air
	4.35	17.3	3.4	0.1	19.5	0.6		“ oxygen
	4.47	17.0	4.7		30.3			“ air

TABLE CLXVIII

(Series 6)

The Influence of Oxygen Administration upon the Percentage Saturation and Oxygen Content of the Blood of Dogs Gassed with Phosgene

(50–60 parts per million) (0.21–0.26 mgm. per liter).

No.	*Time*	*Capacity*	*Arterial content*	*Venous content*	*Arterial percentage saturation*	*Venous percentage saturation*	*Hemoglobin*	*Remarks*
213	9.45	21.9	21.2	13.7	96.7	62.7	130	Normal, breathing air 11/27
								Gassed, 9.22 A.M. 12/2
	10.15	22.3	18.6	12.5	83.4	56.0		breathing air
								Bled 1% body weight 10.15 A.M.
	2.15	21.8	21.2	10.2	97.4	46.3	135	breathing air
	2.45	21.8	22.8	13.0	100.0	56.8	135	" oxygen
								Infusion 1% body weight 4.50 P.M.
	5.05	21.6	20.8	12.0	96.0	55.5	135	breathing air
	5.25	22.3	22.6	14.4	100.0	64.7		" oxygen
211	8.50	20.0	19.0	11.6	95.0	57.8		Normal, breathing air 11/23
								Gassed, 8.54 A.M., 11/25
	9.30	19.7	17.9	5.7	90.4	28.7	140	breathing air
								Bled 1% body weight 9.30 A.M.
	2.05	19.5	17.6	4.6	90.0	23.6	135	breathing air
	2.35	19.5	19.1	8.9	98.0	45.7	140	" oxygen
								Infused 1% body weight 3.12 P.M.
	3.22	19.1	17.5	8.3	92.1	42.5	135	breathing air
	3.50	20.1	18.9	10.6	93.9	52.8	135	" oxygen
	9.40	20.0	16.3	5.8	81.6	29.0	150	" air 11/26
	10.30	19.4	17.6	9.5	91.0	48.8	145	" oxygen
	10.50	19.4	14.8	5.9	75.1	30.2	140	" air
215	9.25	24.6	21.9	12.9	91.3	53.5		Normal, breathing air 12/4
								Gassed, 8.50 A.M. 12/5
								Bled 1% body weight 9.10 A.M.
	9.10	20.5	18.8	1.5	91.7	56.2		breathing air
	2.30	22.1	21.8	12.7	98.6	57.5	135	" "
	2.50	22.5	26.0(?)	12.7	100.0	56.6	130	" oxygen
								Infused 1% body weight 4.00 P.M.
	4.30	24.4	22.1	10.0	90.5	40.8	140	breathing air
	4.50	24.5	25.6	9.1	100.0	37.2	140	" oxygen
	10.30	21.6	14.7	2.8	68.2	13.2	145	" air 12/6
	10.50	21.3	20.2	8.2	95.0	38.6	145	" oxygen

TABLE CLXVIII (Continued)

No.	*Time*	*Capacity*	*Arterial content*	*Venous content*	*Arterial percentage saturation*	*Venous percentage saturation*	*Hemoglobin*	*Remarks*
217	10.00	20.5	19.1	11.8	93.5	57.7	145(?)	Normal, breathing air 12/7
								Gassed, 9.18 A.M.
								Bled 1% body weight 9.45 A.M. 12/9
	9.45	18.6	10.0	12.7	100.0	67.9	145	breathing air
	2.35	16.3	15.2	9.7	93.3	59.4	135	breathing air
	3.40	19.1	18.7	9.5	98.0	50.0	140	“ oxygen
								Infused 1% body weight 4.40 P.M.
	4.49	16.8	14.4	5.4	85.4	32.1	135	breathing air
	5.01	17.5	15.4	6.1	88.0	35.2	135	“ oxygen
	9.50	19.5	17.8	9.5	91.5	48.7	140	“ air 12/10
	9.55	10.2	20.2	9.4	100.0	48.8	140	“ oxygen
	10.45	18.9	17.7	5.7	93.5	31.0		“ air

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